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(54) **DRIVING BEHAVIOR FEEDBACK INTERFACE**

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G06F 19/00 (2011.01)

(52) **U.S. Cl.**
USPC **701/70**; 701/1; 705/7.38

(58) **Field of Classification Search**
None
See application file for complete search history.

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Assistant Examiner — Demetra Smith-Stewart
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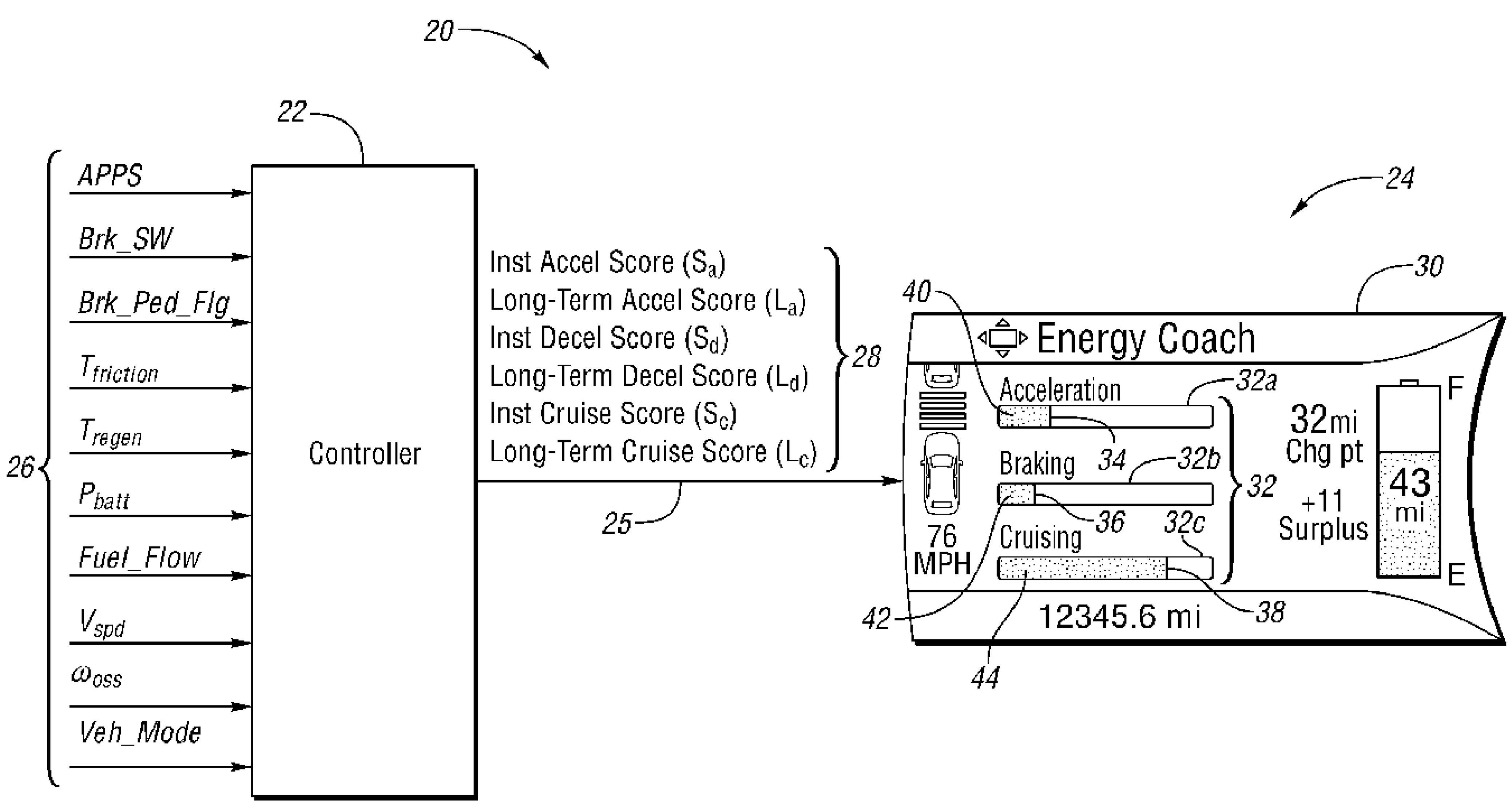
(57) **ABSTRACT**

One or more embodiments of the present application may provide a system and method for monitoring driver inputs and vehicle parameters, assessing a driver's braking deceleration behavior, and providing short-term and/or long-term feedback to the driver relating to the driver's braking deceleration behavior. The braking deceleration behavior feedback can be used to coach future braking deceleration behavior that may translate into better long-term driving habits, which in turn may lead to improvements in fuel economy or vehicle range. Moreover, the braking deceleration behavior feedback can be adapted to a driver based upon how responsive the driver is to the feedback.

20 Claims, 10 Drawing Sheets



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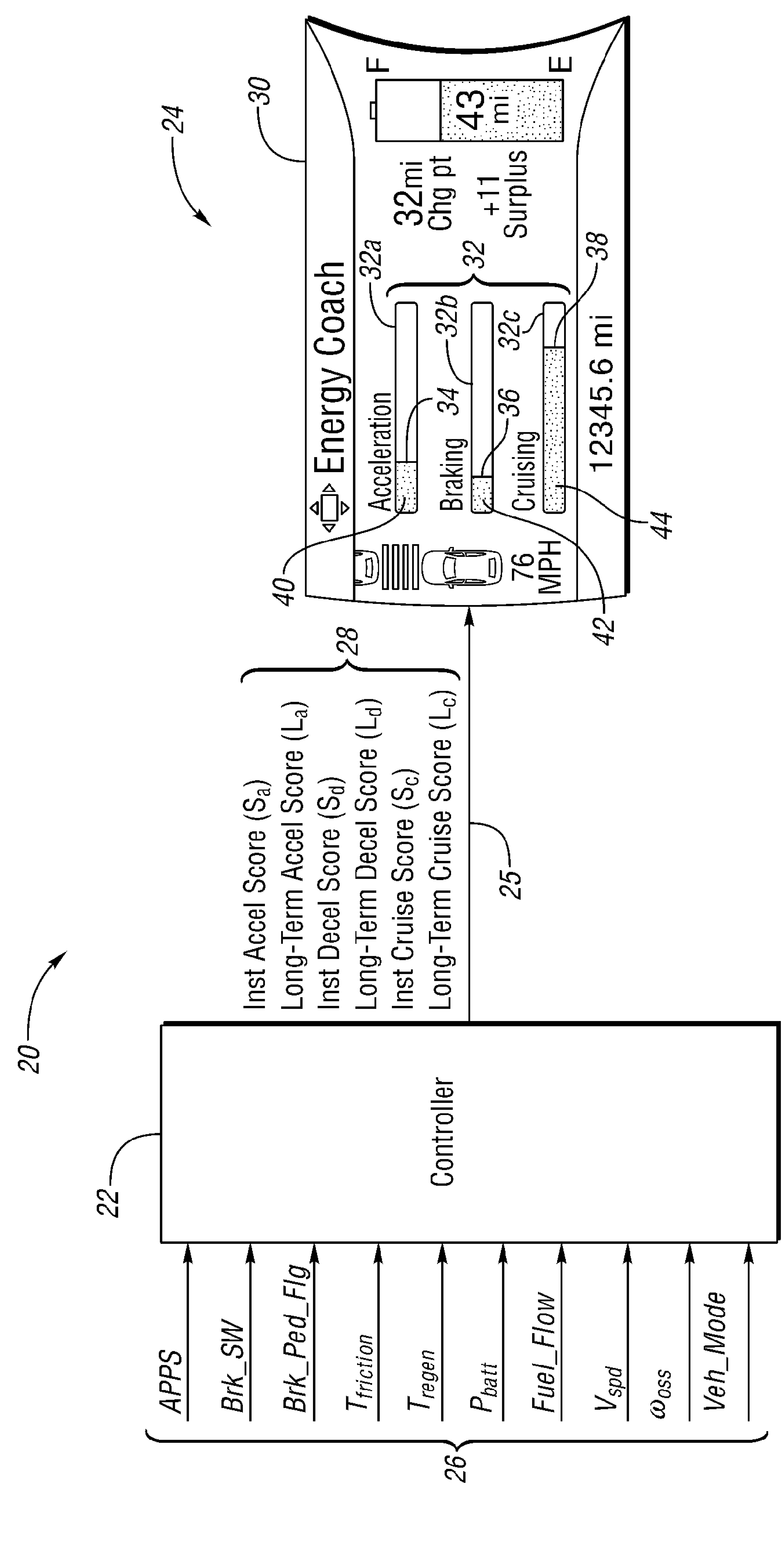
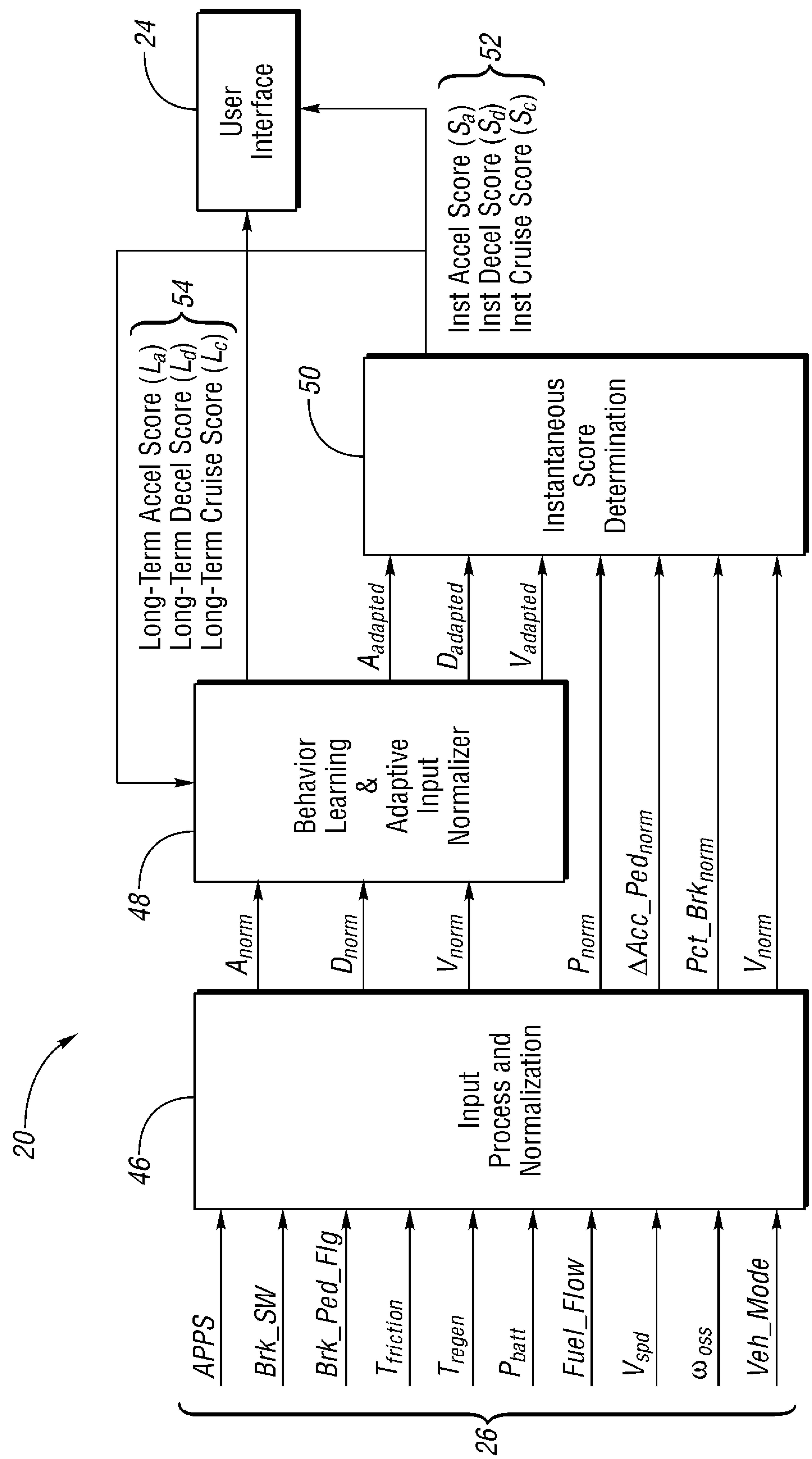

20
22
Controller
APPS
Brk_SW
Brk_Ped_Flg
$T_{friction}$
T_{regen}
P_{batt}
Fuel_Flow
V_{spd}
ω_{oss}
Veh_Mode
26
Inst Accel Score (S_a)
Long-Term Accel Score (L_a)
Inst Decel Score (S_d)
Long-Term Decel Score (L_d)
Inst Cruise Score (S_c)
Long-Term Cruise Score (L_c)
28
25
24
30
Energy Coach
Acceleration
Braking
Cruising
32
32a
32b
32c
34
36
38
40
42
44
76 MPH
12345.6 mi
32mi Chg pt
+11 Surplus
F
E
43 mi

Fig. 1



20
24
User Interface
52
Inst Accel Score (S_a)
Inst Decel Score (S_d)
Inst Cruise Score (S_c)
54
Long-Term Accel Score (L_a)
Long-Term Decel Score (L_d)
Long-Term Cruise Score (L_c)
50
Instantaneous Score Determination
$A_{adapted}$
$D_{adapted}$
$V_{adapted}$
48
Behavior Learning & Adaptive Input Normalizer
A_{norm}
D_{norm}
V_{norm}
P_{norm}
ΔAcc_Ped_{norm}
Pct_Brk_{norm}
V_{norm}
46
Input Process and Normalization
APPS
Brk_SW
Brk_Ped_Flg
$T_{friction}$
T_{regen}
P_{batt}
Fuel_Flow
V_{spd}
ω_{oss}
Veh_Mode
26

Fig. 2

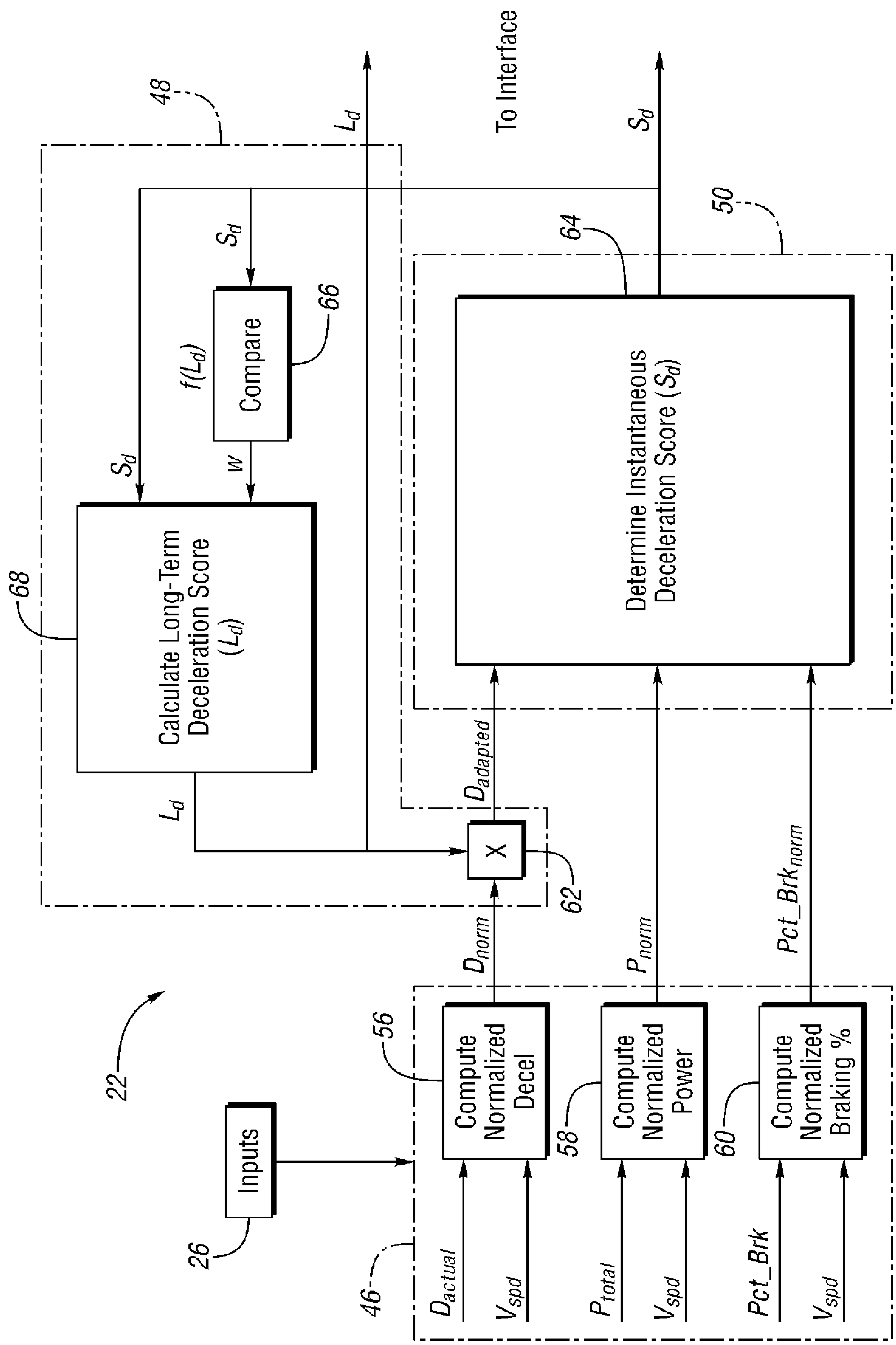

Inputs
26
22
46
D_{actual}
V_{spd}
P_{total}
V_{spd}
Pct_Brk
V_{spd}
Compute Normalized Decel
56
Compute Normalized Power
58
Compute Normalized Braking %
60
D_{norm}
P_{norm}
Pct_Brk_{norm}
X
62
$D_{adapted}$
Determine Instantaneous Deceleration Score (S_d)
64
50
Calculate Long-Term Deceleration Score (L_d)
68
Compare
66
$f(L_d)$
w
S_d
L_d
48
To Interface

Fig. 3

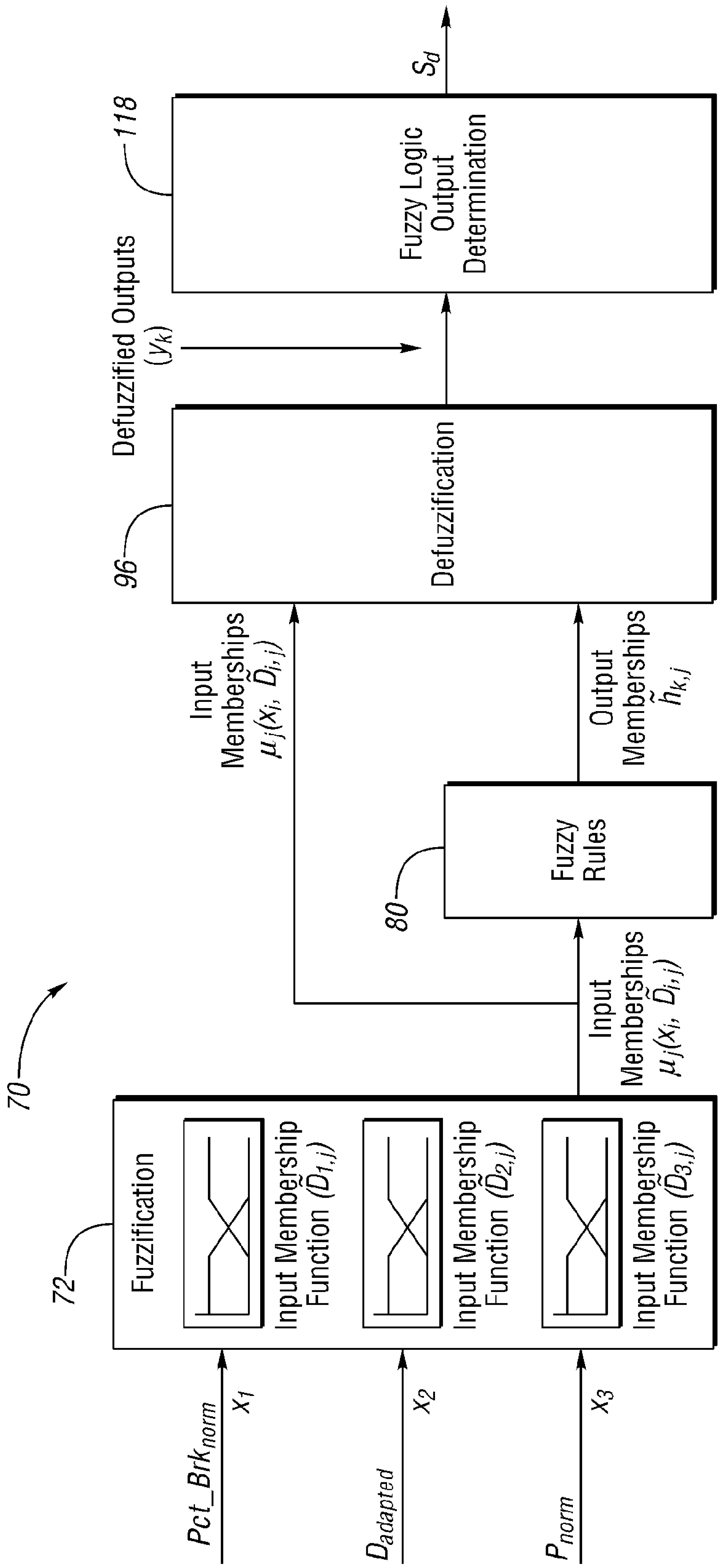

70
72
Fuzzification
Input Membership Function ($\tilde{D}_{1,j}$)
Input Membership Function ($\tilde{D}_{2,j}$)
Input Membership Function ($\tilde{D}_{3,j}$)
Pct_Brk_{norm}
x_1
$D_{adapted}$
x_2
P_{norm}
x_3
Input Memberships $\mu_j(x_i, \tilde{D}_{i,j})$
80
Fuzzy Rules
Output Memberships $\tilde{h}_{k,j}$
Input Memberships $\mu_j(x_i, \tilde{D}_{i,j})$
96
Defuzzification
Defuzzified Outputs (y_k)
118
Fuzzy Logic Output Determination
S_d

Fig. 4

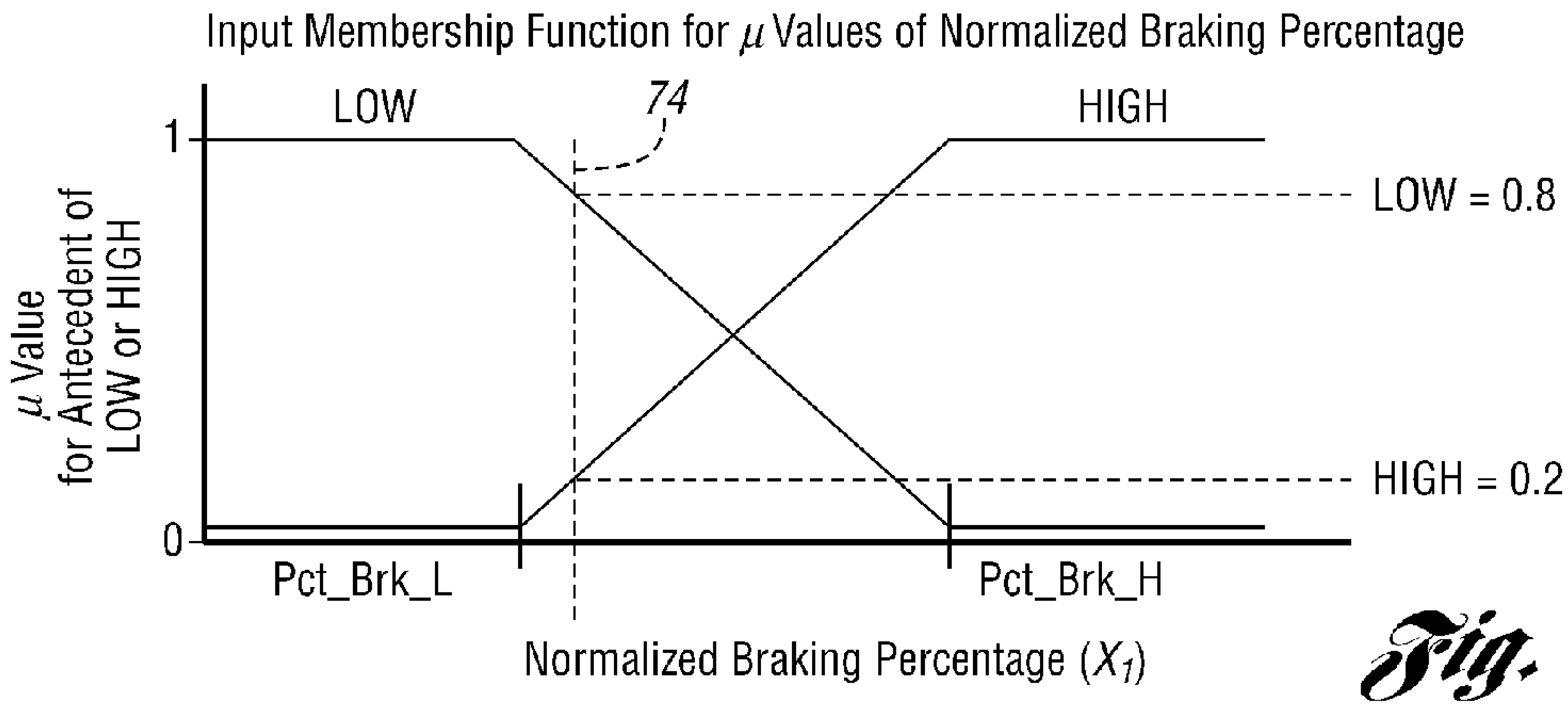


Fig. 5a

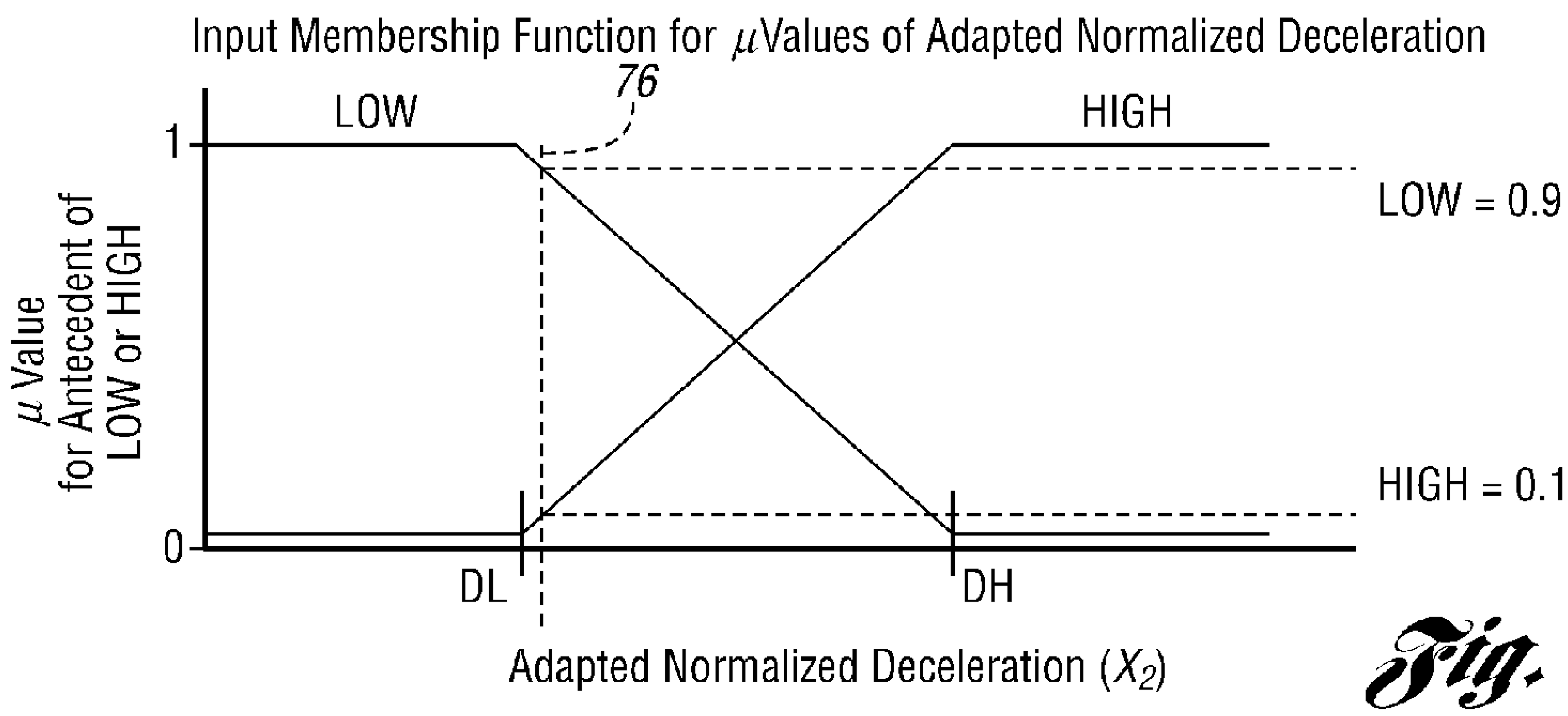


Fig. 5b

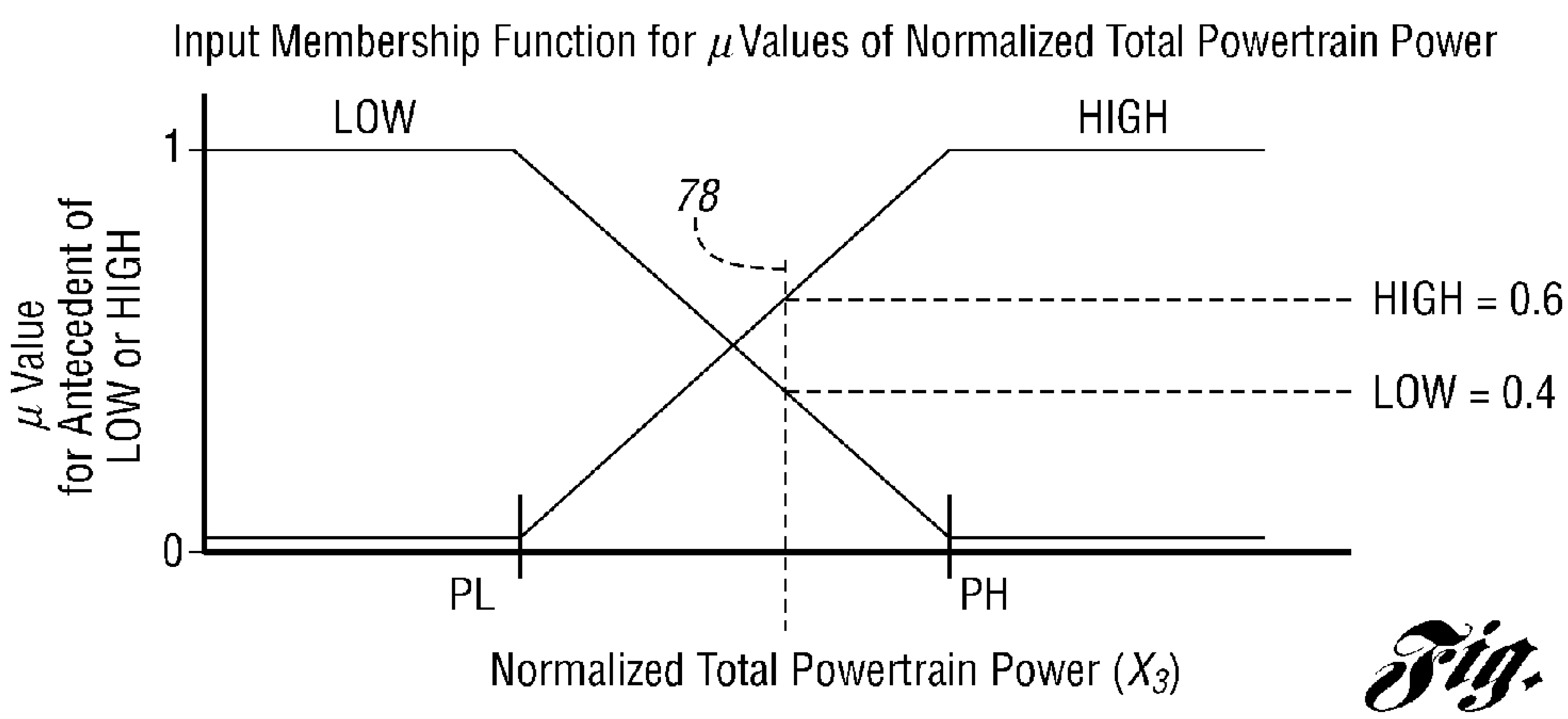


Fig. 5c

82

Rule (j)	Antecedents (for μ value): If Normalized % of Total Braking to Regen Limit (x_1) Is	If Adapted Normalized Deceleration (x_2) Is	If Normalized Total Power (x_3) Is	Consequents (for h value): Then Advised Change in Score (y_1) Is	Then MAX Score Offset (y_2) Is	Then MIN Score Offset (y_3) Is	Comments
1	Low	Low	Low	High	High	Zero	Minimal braking condition where driver braking performance is efficient.
2	Low	Low	High	Low	Low	Zero	Minimal braking condition where total power consumption is high; anticipate for and provide advice to slowly improve driving.
3	Low	High	Low	Low	High	Zero	Minimal braking condition where vehicle deceleration is high; anticipate for to slowly improve driving.
4	Low	High	High	-Low	High	High	Minimal braking condition so predict for inefficient driving.
5	High	Low	Low	-Low	High	One	Braking condition where current vehicle conditions are OK; use predictive actions to prepare for any upcoming inefficiency.
6	High	Low	High	-Low	Low	One	Braking condition where current vehicle conditions are not OK; indicate to driver to quickly improve braking performance.
7	High	High	Low	-High	High	Zero	Friction braking condition where current vehicle conditions are OK; use predictive actions to prepare for any upcoming inefficiency.
8	High	High	High	-High	High	Zero	Braking condition where current vehicle conditions are not OK; indicate to driver to quickly improve braking performance.

84 88 86 90 94

Fig. 6

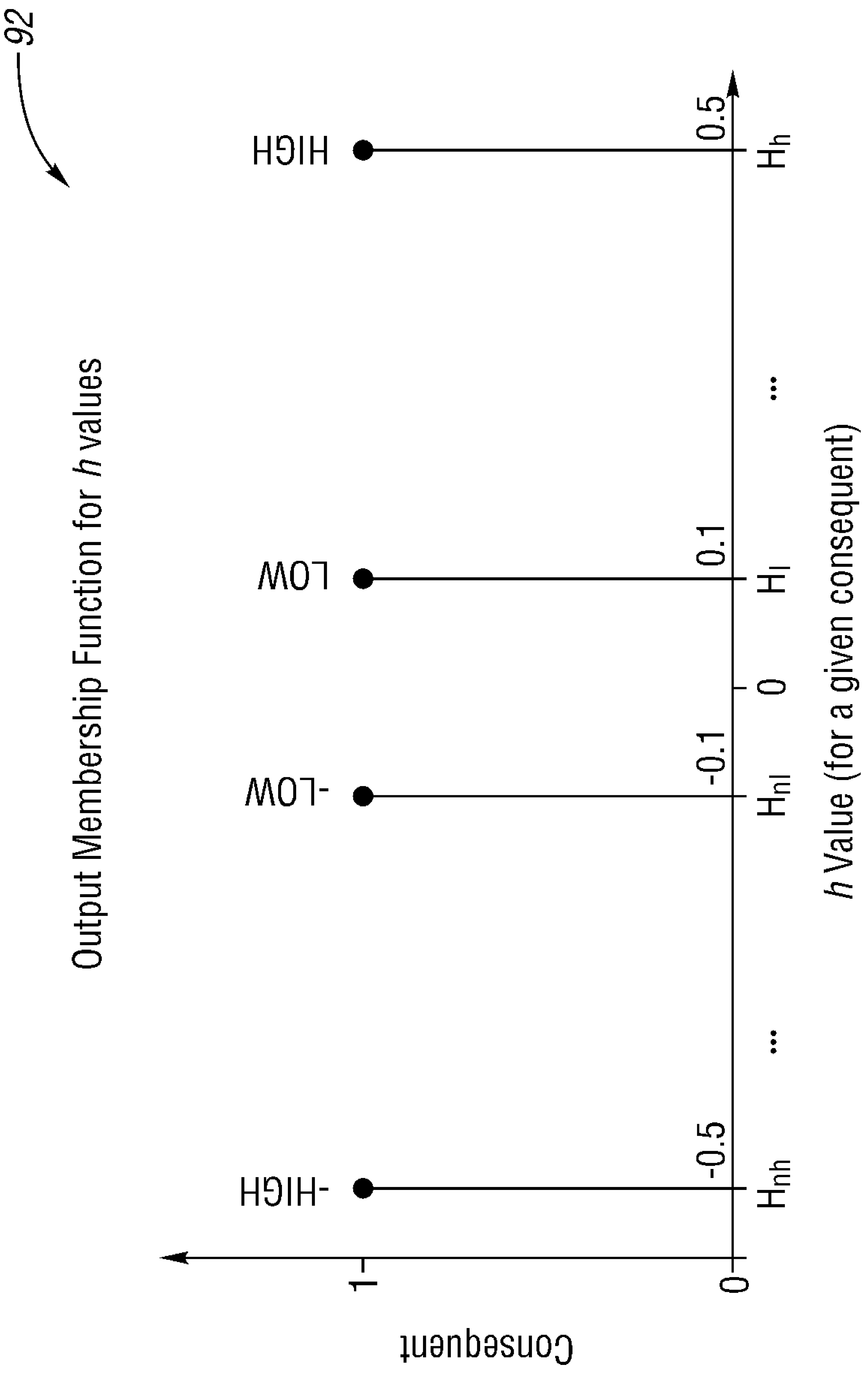

92
Output Membership Function for h values
HIGH
LOW
-LOW
-HIGH
0.5
0.1
0
-0.1
-0.5
H_h
H_l
H_{nl}
H_{nh}
h Value (for a given consequent)
Consequent
1
0

Fig. 7

98 102 104

Rule	x_1	x_2	x_3	*j-th* Rule Operation	
1	0.8 (L)	0.9 (L)	0.4 (L)	0.8 x 0.9 x 0.4	= 0.288
2	0.8 (L)	0.9 (L)	0.6 (H)	0.8 x 0.9 x 0.6	= 0.432
3	0.8 (L)	0.1 (H)	0.4 (L)	0.8 x 0.1 x 0.4	= 0.032
4	0.8 (L)	0.1 (H)	0.6 (H)	0.8 x 0.1 x 0.6	= 0.048
5	0.2 (H)	0.9 (L)	0.4 (L)	0.2 x 0.9 x 0.4	= 0.072
6	0.2 (H)	0.9 (L)	0.6 (H)	0.2 x 0.9 x 0.6	= 0.108
7	0.2 (H)	0.1 (H)	0.4 (L)	0.2 x 0.1 x 0.4	= 0.008
8	0.2 (H)	0.1 (H)	0.6 (H)	0.2 x 0.1 x 0.6	= 0.012 +
				$\sum_{j=1}^{\Omega} \mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})$	= 1.000

106

108 112 114

Rule	y_1	$\tilde{h}_{1,j}$	Fuzzy Implication	
1	High	0.5	x 0.288	= 0.1440
2	Low	0.1	x 0.432	= 0.0432
3	Low	0.1	x 0.032	= 0.0032
4	-Low	-0.1	x 0.048	= -0.0048
5	-Low	-0.1	x 0.072	= -0.0072
6	-Low	-0.1	x 0.108	= -0.0108
7	High	0.5	x 0.008	= 0.0040
8	-High	-0.5	x 0.012	= -0.0060 +
			$\sum_{j=1}^{\Omega} \mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})\,\tilde{h}_{k,j}$	= 0.1656

116

110

$$y_k = \frac{\sum_{j=1}^{\Omega} \mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})\,\tilde{h}_{k,j}}{\sum_{j=1}^{\Omega} \mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})} = \frac{0.1656}{1} = \boxed{0.1656} \quad \text{(for } k = 1\text{)}$$

100

Fig. 8

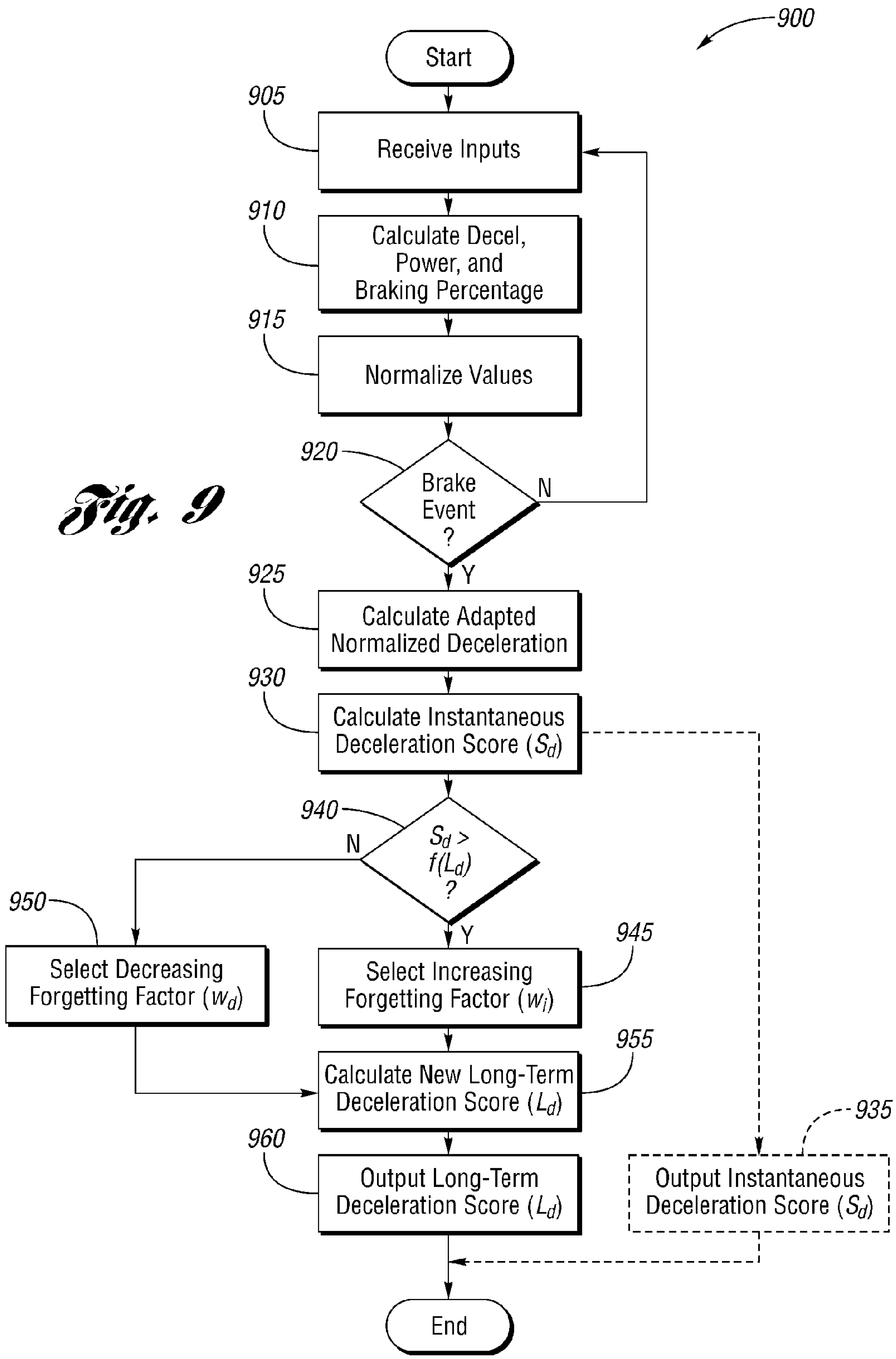

900
Start
905
Receive Inputs
910
Calculate Decel, Power, and Braking Percentage
915
Normalize Values
920
Brake Event ?
N
Y
925
Calculate Adapted Normalized Deceleration
930
Calculate Instantaneous Deceleration Score (S_d)
940
S_d > $f(L_d)$?
N
Y
950
Select Decreasing Forgetting Factor (w_d)
945
Select Increasing Forgetting Factor (w_i)
955
Calculate New Long-Term Deceleration Score (L_d)
960
Output Long-Term Deceleration Score (L_d)
935
Output Instantaneous Deceleration Score (S_d)
End

Fig. 9

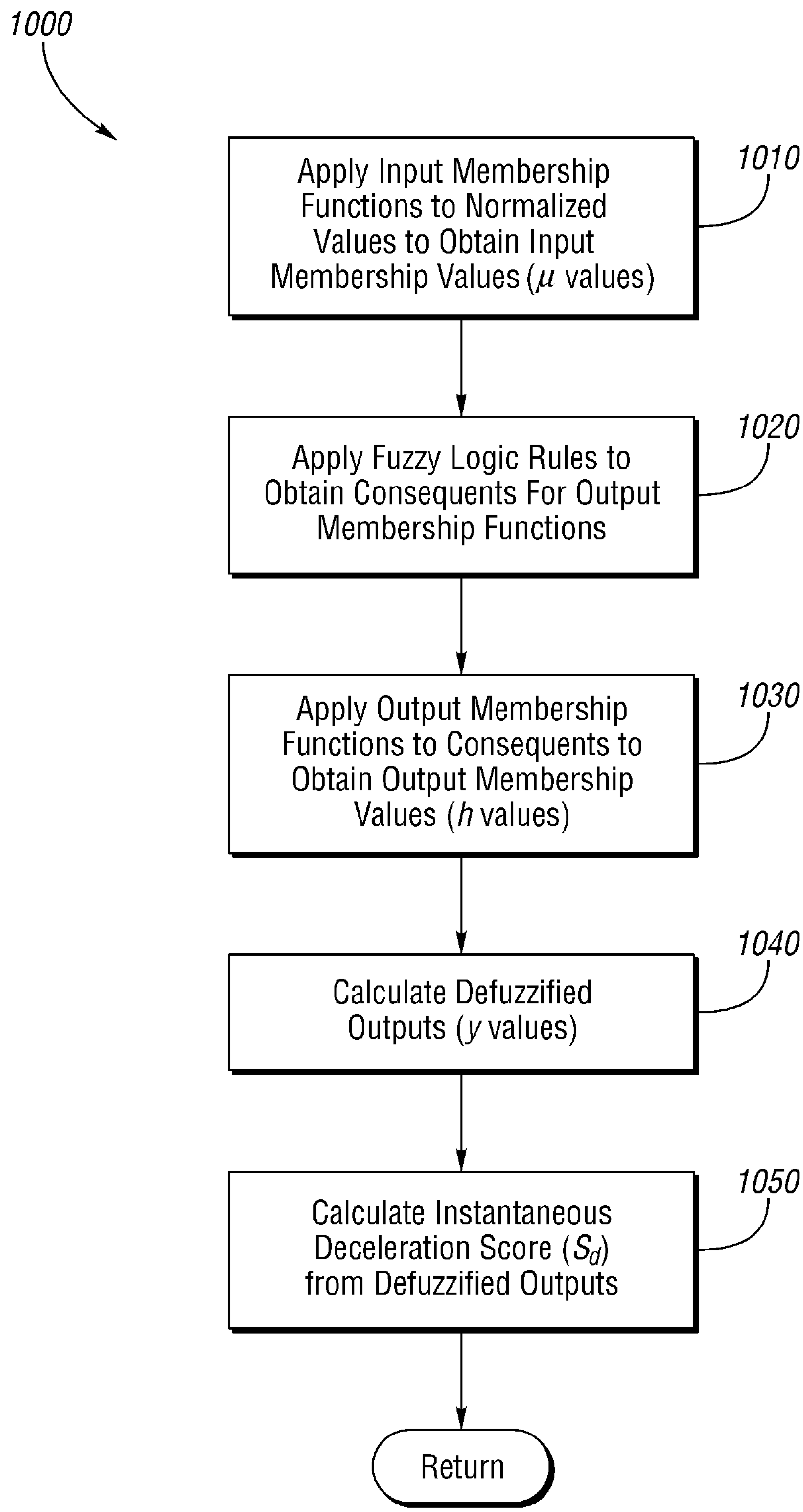

1000
Apply Input Membership Functions to Normalized Values to Obtain Input Membership Values (μ values)
1010
Apply Fuzzy Logic Rules to Obtain Consequents For Output Membership Functions
1020
Apply Output Membership Functions to Consequents to Obtain Output Membership Values (h values)
1030
Calculate Defuzzified Outputs (y values)
1040
Calculate Instantaneous Deceleration Score (S_d) from Defuzzified Outputs
1050
Return

Fig. 10

DRIVING BEHAVIOR FEEDBACK INTERFACE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. provisional Application No. 61/581,938, filed Dec. 30, 2011, the disclosure of which is incorporated in its entirety by reference herein.

TECHNICAL FIELD

One or more embodiments of the present application relate to a system and method for conveying feedback to a driver on the driver's deceleration behavior via a user interface.

BACKGROUND

Vehicles include a number of interfaces, such as gauges, indicators, and various displays to convey information to the user regarding the vehicle's operation and its surroundings. With the advent of new technologies, including technologies found in conventional vehicles as well as in hybrid electric vehicles (HEVs), plug-in hybrid electric vehicle (PHEVs) and battery electric vehicles (BEVs), these interfaces have become more sophisticated. For example, many HEVs incorporate gauges that attempt to provide the driver with information on the various hybrid driving states. Some gauges will indicate to the driver when the vehicle is being propelled by the engine alone, the motor alone, or a combination of the two. Similarly, a display may indicate when the motor is operating as a generator, and is recharging an energy storage device, such as a battery. Regardless of the vehicle type, fuel economy or range of a vehicle still remains an important metric to most vehicle drivers.

In real world driving conditions, driver behavior remains the primary factor affecting fuel economy or range of a vehicle. It is known that some drivers may not be able to achieve desired fuel economy or range, in part because of driving habits. Although it is clear that driving behavior affects the fuel economy or range of a vehicle, it is often unclear how one should drive by taking powertrain and other environmental factors into account in order to improve fuel economy or range. In many cases, drivers are willing to modify their behavior, but are unable to translate recommended techniques into real changes in their driving habits.

SUMMARY

According to one or more embodiments of the present application, a display control system and method for coaching driving deceleration behavior is provided. The control system may include a controller and an interface in communication with the controller. The controller may be configured to receive input indicative of at least vehicle deceleration and powertrain output power. The controller may be further configured to output at least one deceleration score based upon the input. The interface may be configured to display a deceleration feedback indicator indicative of the at least one deceleration score.

The interface may include a deceleration feedback gauge for displaying the deceleration feedback indicator. The interface may be configured to adjust the deceleration feedback indicator within the deceleration feedback gauge based on the at least one deceleration score. The at least one deceleration score indicated by the deceleration feedback indicator may include one of a long-term deceleration score and an instantaneous deceleration score. Moreover, the interface may be further configured to adjust a color of at least a portion of the deceleration feedback gauge based on the other of the long-term deceleration score and the instantaneous deceleration score.

According to one or more embodiments, the input may be further indicative of a braking percentage. The controller may calculate the instantaneous deceleration score based upon the vehicle deceleration, the powertrain output power and the braking percentage. In this regard, the controller may normalize one or more of the vehicle deceleration, the powertrain output power and the braking percentage based upon vehicle speed prior to calculating the instantaneous deceleration score. Moreover, the controller may calculate an adapted deceleration value prior to calculating the instantaneous deceleration score. The adapted deceleration value may be based on the vehicle deceleration and the long-term deceleration score. For instance, the adapted deceleration value may be calculated by multiplying a normalized deceleration value by the long-term deceleration score.

According to one or more embodiments, the instantaneous deceleration score may be calculated using a fuzzy logic algorithm. Furthermore, the long-term deceleration score may be based at least in part upon the instantaneous deceleration score, a previous long-term deceleration score, and a forgetting factor for weighting the instantaneous deceleration score and the previous long-term deceleration score. A value associated with the forgetting factor may be based on a comparison of the instantaneous deceleration score to a function of the long-term deceleration score.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a high-level, functional diagram of a vehicle control system for coaching driving behavior in accordance with one or more embodiments of the present application;

FIG. **2** is an exemplary, functional block diagram of the control system in greater detail;

FIG. **3** is a simplified, schematic block diagram of the controller and related algorithms generally described in FIG. **2** for use in coaching driving deceleration behavior;

FIG. **4** is a functional block diagram illustrating a fuzzy logic control algorithm in accordance with one or more embodiments of the present application;

FIGS. **5***a-c* depict exemplary input membership functions for use in generating input membership values based on a set of fuzzy input variables in accordance with one or more embodiments of the present application;

FIG. **6** is a table illustrating an exemplary set of fuzzy rules in accordance with one or more embodiments of the present application;

FIG. **7** depicts a simplified, exemplary output membership function for determining output membership values in accordance with one or more embodiments of the present application;

FIG. **8** is an exemplary flow diagram an implementation of a defuzzification process using a real-world example in accordance with one or more embodiments of the present application;

FIG. **9** is a simplified, exemplary flow chart depicting a method for conveying driving deceleration behavior feedback in accordance with one or more embodiments of the present application; and

FIG. **10** is a simplified, exemplary flowchart depicting a method for calculating an instantaneous deceleration score in accordance with one or more embodiments of the present application.

DETAILED DESCRIPTION

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms. The figures are not necessarily to scale; some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

One of the main driver factors than can affect the fuel efficiency or range of a vehicle is the braking deceleration behavior as dictated by the driver's brake pedal maneuver. Many drivers are often uncertain how they should drive in order to improve fuel economy or range by taking powertrain and other environmental factors into account. Feedback to drivers on their braking deceleration behavior can impact or improve their future actions to increase fuel economy or range with minimal, if any, effect on the drivability of the vehicle. Real-time braking deceleration behavior feedback can translate into better long-term driving habits.

One or more embodiments of the present application may provide a system and method for monitoring driver inputs and vehicle parameters, assessing a driver's braking deceleration behavior, and providing feedback to the driver relating to the braking deceleration behavior. The braking deceleration behavior feedback can be used to coach the driver's future braking behavior. The braking deceleration behavior coaching may ultimately lead to improvements in the vehicle's power efficiency when the braking deceleration behavior negatively affects or reduces the power efficiency of the vehicle.

The system can provide relatively short-term feedback or advice relating to a driver's braking deceleration behavior. Moreover, the system may monitor the driver's acceptance or rejection of the short-term feedback in order to learn the driver's long-term intentions for using the feedback to modify his or her braking deceleration behavior. Further, the system may provide a long-term score relating to the driver's braking deceleration behavior that may be based, at least in part, upon the driver's acceptance or rejection of the braking deceleration behavior feedback. In this manner, the system can adapt to the driver's long-term intentions regarding use of the braking deceleration behavior coaching to modify driving habits and can provide corresponding feedback that may tend to improve the driver's braking behavior gradually over time. According to one or more embodiments of the present application, the long-term score relating to the driver's braking deceleration behavior may be used to modify the system's vehicle deceleration input, which may be used in generating the short-term feedback when the braking percentage, the vehicle speed, and the deceleration are each above certain thresholds.

Referring now to the drawings, FIG. **1** depicts a high-level, functional diagram of a control system **20** for a vehicle (not shown) for coaching driving behavior in accordance with one or more embodiments of the present application. The control system **20** may include a controller **22** and a user interface **24** that are in communication with each other. Although it is shown as a single controller, the controller **22** may include multiple controllers that may be used to control multiple vehicle systems. For example, the controller **22** may be a vehicle system controller/powertrain control module (VSC/PCM). In this regard, the PCM portion of the VSC/PCM may be software embedded within the VSC/PCM, or it can be a separate hardware device. The controller **22** generally includes any number of microprocessors, ASICs, ICs, memory (e.g., FLASH, ROM, RAM, EPROM and/or EEPROM) and software code to co-act with one another to perform a series of operations. The controller **22** may communicate with other controllers (e.g., a battery energy control module, transmission control module, etc.) and the user interface **24** over a hardline vehicle connection, such as a BUS **25**, using a common bus protocol (e.g., CAN), or may communicate wirelessly with other vehicle devices using a wireless transceiver (not shown).

The controller **22** may receive input signals **26** and may generate one or more instantaneous and/or long-term driving behavior feedback signals **28** in response to the input signals **26**. The controller **22** may transmit this information to the user interface **24**, which in turn conveys the information to the driver. The driver may then use the driving behavior feedback to improve driving habits, such as those relating to acceleration, deceleration and cruising.

The user interface **24** may include at least one display **30** and associated circuitry, including hardware and/or software, necessary to communicate with the controller **22** and operate the display. The display **30** may be generally used to convey relevant vehicle content to a driver of the vehicle including, for example, driving behavior information or other information relating to the operation of the vehicle.

The display **30** may be disposed within a dashboard (not shown) of the vehicle, such as in an instrument panel or center console area. Moreover, the display **30** may be part of another user interface system, such as a navigation system, or may be part of a dedicated information display system. The display **30** may be a liquid crystal display (LCD), a plasma display, an organic light emitting display (OLED), or any other suitable display. The display **30** may include a touch screen for receiving driver input associated with selected areas of the display. The user interface **24** or display **30** may also include one or more buttons (not shown), including hard keys or soft keys, for effectuating driver input.

The driving behavior feedback signals **28** generated by the controller **22** may correspond to a score or other relative metric that may be used to evaluate aspects of a driver's driving behavior, such as acceleration behavior, deceleration (braking) behavior and cruising speed behavior. According to one or more embodiments, the driving behavior feedback signals **28** may include one or more of the following driving behavior scores: an instantaneous acceleration score (S_a), a long-term acceleration score (L_a), an instantaneous deceleration score (S_d), a long-term deceleration score (L_d), an instantaneous cruising speed score (S_c), and a long-term cruising speed score (L_c).

The display **30** may include one or more driving behavior feedback gauges **32** for conveying the various driving behavior feedback scores. In particular, the display **30** may include an acceleration feedback gauge **32**a associated with the instantaneous acceleration score (S_a) and/or the long-term acceleration score (L_a). The display **30** may further include a deceleration feedback gauge **32**b associated with the instantaneous deceleration score (S_d) and/or the long-term deceleration score (L_d). Furthermore, the display **30** may include a cruising speed feedback gauge **32**c associated with the instantaneous cruising speed score (S_c) and/or the long-term cruising speed score (L_c). As shown in FIG. **1**, each driving behavior feedback gauge **32** may be a bar gauge including at least one feedback indicator corresponding to at least one of the driving behavior feedback signals **28**. For instance, the acceleration feedback gauge **32***a* may include an acceleration feedback indicator **34** corresponding to at least one of the instantaneous acceleration score (S_a) and the long-term acceleration score (L_a). Similarly, the deceleration feedback gauge **32***b* may include a deceleration feedback indicator **36** corresponding to at least one of the instantaneous deceleration score (S_d) and the long-term deceleration score (L_d). The cruising speed feedback gauge **32***c* may include a cruising speed feedback indicator **38** corresponding to at least one of the instantaneous cruising speed score (S_c) and the long-term cruising speed score (L_c). Each feedback indicator may define a corresponding bar segment illuminated or otherwise displayed by the display **30**. Accordingly, the driving behavior score corresponding to each feedback indicator may define the length of its associated bar segment. For example, the acceleration feedback indicator **34** may define an acceleration bar segment **40** on the acceleration feedback gauge **32***a*, the deceleration feedback indicator **36** may define a deceleration bar segment **42** on the deceleration feedback gauge **32***b*, and the cruising speed feedback indicator **38** may define a cruising speed bar segment **44** on the cruising speed feedback gauge **32***c*. Although each driving behavior feedback gauge **32** may be implemented using a bar gauge or similar graphic, various alternate types of gauges and/or indicators may also be employed to convey the driving behavior scores. Some non-limiting examples may include numerical indicators, needle gauges, and the like.

One or more embodiments of the present application may be implemented in all types of vehicles, including vehicles having different powertrain configurations. For example, one or more embodiments may be implemented in hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), or conventional vehicles, such as those powered solely by an internal combustion engine. HEVs may refer to vehicles powered by an engine and/or one or more electric motors. BEVs may refer to all-electric vehicles propelled by one or more electric motors without assistance from an internal combustion engine. PHEVs may refer to hybrid electric vehicles primarily powered by one or more electric motors. PHEVs and BEVs may be connected to an external power supply for charging a vehicle battery that supplies electrical power to the motors.

In order to provide one or more of the driving behavior feedback signals **28** referenced above, one or more of the input signals **26** received by the controller **22** may be generally indicative of vehicle speed (V_{spd}), actual vehicle acceleration (A_{actual}), and/or actual vehicle deceleration (D_{actual}). In addition, one or more of the input signals **26** may be generally indicative of total powertrain output power (P_{total}), accelerator pedal position change (ΔAcc_Ped) and/or braking percentage (Pct_Brk). The input signals **26** received by the controller **22** may be used in one or more algorithms contained within, or otherwise executed by, the controller **22** for determining input values such as vehicle acceleration (A_{actual}), deceleration (D_{actual}), total powertrain output power (P_{total}), accelerator pedal position change (ΔAcc_Ped) and/or braking percentage (Pct_Brk). Although generally described as inputs received directly by the controller **22**, one or more of the input signals **26** may be merely indicative of inputs generally used in controller algorithms for generating the driving behavior feedback. To this end, exemplary input signals may include an accelerator pedal position signal (APPS), a brake switch signal (Brk_SW) and/or a brake pedal flag signal (Brk_Ped_Flg), friction braking torque ($T_{friction}$), regenerative braking torque (T_{regen}), high-voltage (HV) battery power (P_{batt}), fuel flow rate (Fuel_Flow), vehicle speed (V_{spd}) or output shaft speed (ω_{oss}), vehicle mode (Veh_Mode), and the like.

The inputs may be received directly as input signals from individual systems or sensors (not shown), or indirectly as input data over the CAN bus **25**. The input signals **26** received by the controller **22** may be dependent on the powertrain technology employed in a particular vehicle. For instance, in conventional vehicle applications, the input signals relating to the HV battery power (P_{batt}) or regenerative braking torque (T_{regen}), for example, may not be present or applicable in generating the driving behavior feedback signals **28**. Similarly, in BEV applications, an input signal corresponding to the fuel flow rate (Fuel_Flow) would not be applicable.

The controller **22** may determine the actual vehicle acceleration (A_{actual}) and deceleration (D_{actual}) from the actual vehicle speed (V_{spd}) or output shaft speed (ω_{oss}). The controller **22** may determine the total powertrain output power (P_{total}) a number of ways depending upon the powertrain configuration. For instance, the total powertrain output power (P_{total}) in HEV and PHEV applications may be the sum of the battery power (P_{batt}) from a high voltage battery and fuel power (P_{fuel}) as set forth below:

$$P_{total}=P_{batt}+P_{fuel} \qquad \text{Eq. 1}$$

The fuel power (P_{fuel}) may be calculated using the value from the fuel flow rate (Fuel_Flow) and a fuel density (Fuel_Density) according to Eq. 2 set forth below:

$$P_{fuel}=\text{Fuel\_Flow}\times\text{Fuel\_Density} \qquad \text{Eq. 2}$$

In BEV applications, however, the total powertrain output power (P_{total}) may be based solely on the battery power (P_{batt}):

$$P_{total}=P_{batt} \qquad \text{Eq. 3}$$

In conventional powertrain applications, the total powertrain output power (P_{total}) may be based solely on the fuel power (P_{fuel}):

$$P_{total}=P_{fuel} \qquad \text{Eq. 4}$$

The controller **22** may determine the accelerator pedal position change (ΔAcc_Ped) from the accelerator pedal position signal (APPS), which may represent a driver request for wheel torque/power. Therefore, the accelerator pedal position change (ΔAcc_Ped) may be indicative of the driver's accelerator pedal response.

FIG. **2** is an exemplary, functional block diagram of the control system **20** in greater detail. As seen therein, the controller **22** may include a plurality of interrelated algorithms, represented as distinct blocks, for generating the driving behavior feedback signals **28**. Although several of the interrelated algorithms have been divided up schematically in FIG. **2** for illustrative purposes, they me be combined into one larger algorithm for generating the driving behavior feedback signals **28** transmitted to the user interface **24**. As shown in FIG. **2**, the input signals **26** described with respect to FIG. **1** may be generally received at an input process and normalization block **46**. Within the input process and normalization block **46**, one or more of the input signals **26** may be processed to obtain the values for vehicle acceleration (A_{actual}), deceleration (D_{actual}), total powertrain output power (P_{total}), accelerator pedal position change (ΔAcc_Ped), braking percentage (Pct_Brk) or the like, as described above. Moreover, the vehicle acceleration (A_{actual}) and deceleration (D_{actual}) may be modified as a function of vehicle speed (V_{spd}) to obtain a normalized acceleration value (A_{norm}) and a normalized deceleration value (D_{norm}), respectively.

The total powertrain output power (P_{total}) may also be modified as a function of vehicle speed (V_{spd}) to generate a normalized total powertrain output power value (P_{norm}). Similarly, the accelerator pedal position change (ΔAcc_Ped) may also be modified as a function of vehicle speed (V_{spd}) to obtain a normalized accelerator pedal position change value (ΔAcc_Ped_{norm}). In some instances, the vehicle speed (V_{spd}) itself may be normalized to obtain a normalized vehicle speed (V_{norm}).

Like the total powertrain output power, the controller **22** may determine braking percentage (Pct_Brk) differently based on the powertrain configuration. For HEVs, PHEVs, and BEVs, the braking percentage (Pct_Brk) may be based upon a ratio of regenerative braking torque (T_{regen}) to the sum of friction braking torque ($T_{friction}$) and regenerative braking torque (T_{regen}). For instance, the braking percentage (Pct_Brk) may be determined by a filtered unity minus the aforementioned ratio, as set forth in Eq. 5 below:

$$\text{Pct\_Brk} = 1 - \frac{T_{regen}}{T_{friction} + T_{regen}} \qquad \text{Eq. 5}$$

In general, a relatively low braking percentage may indicate that braking is mostly done with regenerative braking. Conversely, a relatively high braking percentage may indicate that braking is mostly done with friction braking.

For conventional vehicles, the braking percentage (Pct_Brk) may be determined from one or more of the brake pedal signals (e.g., Brk_SW and/or Brk_Ped_Flg). As understood by one of ordinary skill in the art, the brake switch signal (Brk_SW) may be an input that indicates when the brake pedal is first being pressed. The brake pedal flag signal (Brk_Ped_Flg) may be a redundant brake pedal input that indicates when the brake pedal is being pressed beyond a point signaled by the brake switch signal (Brk_SW). In some applications, only one brake pedal signal may be available and, thus, the signals may be substituted for one another. According to one or more embodiments, the braking percentage (Pct_Brk) in conventional vehicles may be a slowly filtered weighted sum of the brake pedal switches. In general, if one of the brake pedal switches is active, the braking percentage may be relatively low; if two of the brake pedal switches are active, then the braking percentage may be relatively high. The braking percentage (Pct_Brk) may also be modified as a function of vehicle speed (V_{spd}) to obtain a normalized braking percentage value (Pct_Brk_{norm}).

The acceleration, deceleration, vehicle speed, total powertrain output power, accelerator pedal position change and braking percentage may be normalized with respect to vehicle speed because a vehicle may behave differently at lower speeds than it does at higher speeds. Moreover, the system may want to account for the vehicle speed when determining the driving behavior feedback signals **28**. For instance, the system may want to deemphasize a driver's pedal response at low speeds. Accordingly, the controller **22** may calculate the normalized accelerator pedal position change (ΔAcc_Ped_{norm}) to adjust for vehicle speed. Also, the maximum total powertrain output power (P_{max}) may generally be lower at lower speeds and the maximum vehicle acceleration (A_{max}) may generally be higher at lower speeds. Normalization of these input values can allow for the system to take vehicle speed into account when providing driving behavior feedback.

The controller **22** may further include a behavior learning and adaptive input normalizer block **48** and an instantaneous score determination block **50**. The normalized outputs of the input process and normalization block **46** may become inputs to the behavior learning and adaptive input normalizer block **48** and/or the instantaneous score determination block **50**. At the behavior learning and adaptive input normalizer block **48**, the controller **22** may monitor a driver's instantaneous driving behavior via one or more instantaneous driving behavior feedback signals **52** (e.g., the instantaneous acceleration score (S_a), the instantaneous deceleration score (S_d), or the instantaneous cruising speed score (S_c)) output by the instantaneous score determination block **50**. The instantaneous driving behavior feedback signals **52** may also be transmitted to the user interface **24**. The controller **22** may evaluate the driver's general acceptance or rejection of short-term driving behavior feedback based on the instantaneous driving behavior feedback signals **52**. In this manner, the controller **22** may learn or adapt to the driver's long-term driving behavior intentions based upon whether the driver is responsive to the feedback or generally ignores the feedback.

Moreover, the controller **22** may generate one or more long-term driving behavior feedback signals **54** (e.g., the long-term acceleration score (L_a), the long-term deceleration score (L_d), or the long-term cruising speed score (L_c)), which may be transmitted to the user interface **24**. Additionally, the long-term driving behavior feedback signals **54** may be used to further modify the normalized inputs for acceleration, deceleration and vehicle speed. For example, in one or more embodiments, the controller **22** may adapt the normalized deceleration input (D_{norm}) based on whether the driver is responsive to braking deceleration behavior feedback. In this regard, the normalized deceleration (D_{norm}) may be multiplied by the long-term deceleration score (L_d) at the behavior learning and adaptive input normalizer block **48** to generate an adapted normalized deceleration value ($D_{adapted}$). The controller **22** may also modify the normalized inputs for acceleration and/or vehicle speed in a similar manner at the behavior learning and adaptive input normalizer block **48** to generate an adapted normalized acceleration ($A_{adapted}$) and an adapted normalized vehicle speed ($V_{adapted}$), respectively.

In general, the system may convey short-term and/or long-term driving behavior feedback during particular driving behavior events. For instance, the system may convey driving acceleration behavior feedback when the controller **22** determines that a qualifying acceleration event is occurring or has just occurred. According to one or more embodiments, the controller **22** may detect the occurrence of an acceleration event when accelerator pedal position is above a pedal position threshold, vehicle speed is above a speed threshold, and vehicle acceleration is above an acceleration threshold. The system may convey braking deceleration behavior feedback when the controller **22** determines that a qualifying deceleration (braking) event is occurring or has just occurred. According to one or more embodiments, the controller **22** may detect the occurrence of a deceleration event when the braking percentage is above a braking percentage threshold, vehicle speed is above a speed threshold, and vehicle deceleration is above a deceleration threshold. The system may convey cruising speed behavior feedback when the controller **22** determines that a cruising event is occurring. The controller **22** may detect the occurrence of a cruising event when no acceleration or deceleration events are occurring and the vehicle speed is above a minimum speed threshold. According to one or more embodiments, the controller **22** may convey cruising speed behavior feedback when the vehicle acceleration is below an acceleration threshold and the vehicle deceleration is below a deceleration threshold. The long-term driving behavior feedback signals **54** may be used to further modify or adapt the normalized inputs for acceleration, deceleration and vehicle speed, as described above, when an acceleration event, a deceleration event, or a cruising event is detected.

The adapted normalized acceleration ($A_{adapted}$) can be used in calculating future instantaneous acceleration scores (S_a). To this end, the adapted normalized acceleration ($A_{adapted}$) may be received as an input to the instantaneous score determination block **50**. Similarly, the adapted normalized deceleration ($D_{adapted}$) and adapted normalized vehicle speed ($V_{adapted}$) can be used in calculating future instantaneous deceleration scores (S_d) and instantaneous cruising speed scores (S_c), respectively. Accordingly, the adapted normalized deceleration ($D_{adapted}$) and adapted normalized vehicle speed ($V_{adapted}$) may also be received as inputs to the instantaneous score determination block **50**. As shown, the instantaneous score determination block **50** may also receive additional inputs that may be used to calculate the instantaneous driving behavior scores. For example, the normalized total powertrain output power (P_{norm}), the normalized accelerator pedal position change (ΔAcc_Ped_{norm}), the normalized braking percentage (Pct_Brk_{norm}), and the normalized vehicle speed (V_{norm}) may be inputs to the instantaneous score determination block **50**.

According to one or more embodiments of the present application, the instantaneous score determination block **50** may include a fuzzy logic controller and/or algorithm for generating one or more of the instantaneous driving behavior feedback signals **52**. As previously described, the instantaneous driving behavior feedback signals **52** may be received at the behavior learning and adaptive input normalizer block **48** in order to evaluate the driver's general acceptance or rejection of the driving behavior feedback and provide long-term driving behavior feedback signals **54** to the user interface **24**. In one or more embodiments, the instantaneous driving behavior feedback signals **52** may also be transmitted to the user interface **24** for display purposes along with the long-term driving behavior feedback signals **54**.

FIG. **3** illustrates a simplified, schematic block diagram of the controller algorithms generally described in FIG. **2** for use in coaching braking behavior. As shown, the controller **22** may generally include the input process and normalization block **46**, the behavior learning and adaptive input normalizer block **48**, and the instantaneous score determination block **50**. At the input process and normalization block **46**, the controller **22** may receive one or more of the input signals **26**. As previously described, the one or more input signals **26** may be indicative of the vehicle deceleration (D_{actual}), total powertrain output power (P_{total}), braking percentage (Pct_Brk), and vehicle speed (V_{spd}). Moreover, the vehicle deceleration, total powertrain output power, and braking percentage may each be normalized as a function of the vehicle speed. In this regard, the controller **22** may compute the normalized deceleration (D_{norm}) at block **56** in response to the deceleration (D_{actual}) and vehicle speed (V_{spd}) inputs. In order to compute the normalized deceleration (D_{norm}), the controller **22** may determine a maximum deceleration (D_{max}) value for the vehicle at the current vehicle speed. The maximum deceleration may be obtained in any number of ways as would be understood by one of ordinary skill in the art (e.g., a look-up table, a deceleration curve, etc.). Once the maximum deceleration (D_{max}) is determined, the normalized deceleration (D_{norm}) may be computed by dividing the actual deceleration (D_{actual}) by the maximum deceleration (D_{max}):

$$D_{norm}=\frac{D_{actual}}{D_{max}} \quad \text{Eq. 6}$$

The controller **22** may compute the normalized total powertrain output power (P_{norm}) at block **58** in response to the total powertrain output power (P_{total}) and vehicle speed (V_{spd}) inputs. In order to compute the normalized total powertrain output power (P_{norm}), the controller **22** may determine a maximum powertrain output power (P_{max}) value for the vehicle at the current vehicle speed. The maximum powertrain output power may be obtained in any number of ways as would be understood by one of ordinary skill in the art (e.g., a look-up table, a power curve, etc.). Once the maximum powertrain output power (P_{max}) is determined, the normalized total powertrain output power (P_{norm}) may be computed by dividing the total powertrain output power (P_{total}) by the maximum powertrain output power (P_{max}):

$$P_{norm}=\frac{P_{total}}{P_{max}} \quad \text{Eq. 7}$$

The controller **22** may compute the normalized braking percentage (Pct_Brk_{norm}) at block **60** in response to the braking percentage (Pct_Brk) and vehicle speed (V_{spd}) inputs. In order to compute the normalized braking percentage (Pct_Brk_{norm}), the controller **22** may determine a maximum braking percentage (Pct_Brk_{max}) value recognized by the control system **20** at the current vehicle speed. The maximum braking percentage may be obtained in any number of ways as would be understood by one of ordinary skill in the art (e.g., a look-up table, a braking response curve, etc.). Once the maximum braking percentage (Pct_Brk_{max}) is determined, the normalized braking percentage (Pct_Brk_{norm}) may be computed by dividing the braking percentage (Pct_Brk) by the maximum braking percentage (Pct_Brk_{max}):

$$Pct\_Brk_{norm}=\frac{Pct\_Brk}{Pct\_Brk_{max}} \quad \text{Eq. 8}$$

As previously described, the braking deceleration behavior feedback may generally be provided during vehicle braking events. Accordingly, the long-term deceleration behavior feedback signal may be used to further modify the normalized input for deceleration (D_{norm}) when the braking percentage is above a threshold, vehicle speed is above a threshold, and vehicle deceleration is above a threshold. To this end, the normalized deceleration (D_{norm}) generated at block **56** may be multiplied by the long-term deceleration score (L_d) at multiplication junction **62** to produce the adapted normalized deceleration ($D_{adapted}$). The algorithm for generating the long-term deceleration score (L_d) is described in greater detail below. The controller **22** may determine the instantaneous deceleration score (S_d) at block **64**. The adapted normalized deceleration ($D_{adapted}$), output from multiplication junction **62**, may be an input to the instantaneous deceleration score determination block **64**. The normalized total powertrain output power (P_{norm}) and the normalized braking percentage (Pct_Brk_{norm}) may also be inputs to the instantaneous deceleration score determination block **64**.

According to one or more embodiments of the present application, the instantaneous deceleration score (S_d) may be transmitted to the user interface **24** and displayed via the display **30**. Additionally, the instantaneous deceleration score

(S_d) may be compared to a function of the long-term deceleration score ($f(L_d)$) at block **66**. Since the long-term deceleration score (L_d) may be based on the instantaneous deceleration score (S_d), the controller **22** can determine whether the driver's instantaneous braking behavior will generally increase or decrease the long-term deceleration score (L_d). Further, the controller **22** may select a forgetting factor (w) based on the comparison between the instantaneous deceleration score (S_d) and the function of the long-term deceleration score (L_d). For instance, if the instantaneous deceleration score (S_d) is greater than the long-term deceleration score (L_d), then it may be determined that the long-term deceleration score (L_d) will be increasing. If the long-term deceleration score (L_d) will be increasing, the controller **22** may output an increasing forgetting factor (w_i) at comparison block **66**. On the other hand, if the instantaneous deceleration score (S_d) is less than the long-term deceleration score (L_d), then it may be determined that the long-term deceleration score (L_d) will be decreasing. In this case, the controller **22** may output a decreasing forgetting factor (w_d) at comparison block **66**. Once the appropriate forgetting factor (w) is determined, the controller **22** may calculate a new long-term deceleration score (L_d) at block **68** based upon the previous long-term deceleration score, the instantaneous deceleration score, and the applicable forgetting factor. According to one or more embodiments of the present application, the new long-term deceleration score may be calculated according to Eq. 9 shown below:

$$L_{d(n)}=L_{d(n-1)}(w)+S_d(1-w) \qquad \text{Eq. 9}$$

Where:

$L_{d(n)}$=the new long-term deceleration score

$L_{d(n-1)}$=the previous long-term deceleration score

S_d=the instantaneous deceleration score

w=the forgetting factor (e.g., w_i or w_d)

The term "long-term" in the long-term deceleration score (L_d) may be a relative one. With respect to the instantaneous deceleration score (S_d), the long-term deceleration score (L_d) may provide drivers with relatively long-term feedback on their driving behavior. In this regard, the long-term deceleration score (L_d) may reflect overall barking deceleration behavior over a moving period of several seconds to several minutes or even hours. The value of the forgetting factor (w) may be chosen to reflect the length of the moving period. The higher the forgetting factor, the greater the weight that may be placed on the long-term deceleration score (L_d). According to one or more embodiments, the increasing forgetting factor (w_i) may be set greater than the decreasing forgetting factor (w_d) so that the instantaneous deceleration score (S_d) may have less impact on the long-term deceleration score (L_d) when the long-term deceleration score is increasing (i.e., $L_d<S_d$).

An increasing long-term deceleration score (L_d) may be an indication that the driver is accepting or otherwise responding to the braking deceleration behavior feedback. A decreasing long-term deceleration score (L_d) may provide an indication that the driver is generally rejecting or otherwise ignoring the braking deceleration behavior feedback. If the driver generally ignores the braking deceleration behavior feedback, such that over time the driver may have a relatively low long-term deceleration score (L_d), then the system may adapt the braking deceleration behavior feedback it provides so as to be less critical of inefficient braking behavior. Stated differently, the feedback conveyed by the system for relatively poor braking deceleration behavior events may not be as penal or otherwise adversely affect the long-term deceleration score (L_d) for routinely aggressive drivers, that tend not to heed the braking behavior coaching, as compared to drivers with traditionally good braking deceleration behavior. Thus, if the driver is generally receptive to the braking deceleration behavior feedback by modifying his or her braking behavior accordingly, then the system may be more sensitive with respect to future braking deceleration behavior events in order to continue encouraging further behavior modification. To this end, the controller **22** may use the long-term deceleration score (L_d) to adapt the normalized deceleration input to the instantaneous deceleration score determination block **64** so that the braking deceleration behavior feedback is more critical of, or responsive to, relatively nonaggressive drivers. As previously described, the normalized deceleration input (D_{norm}) may be multiplied by the long-term deceleration score (L_d) at multiplication junction **62** to generate the adapted normalized deceleration input ($D_{adapted}$).

FIG. **4** is functional block diagram illustrating a fuzzy logic control algorithm **70** in accordance with one or more embodiments of the present application. The fuzzy logic control algorithm **70** may correspond to determination block **64** in FIG. **3** for determining the instantaneous deceleration score (S_d). The fuzzy logic control algorithm **70** may be carried out using a fuzzy logic controller. The fuzzy logic controller may be contained within the controller **22**, and may be implemented in hardware and/or software control logic as described in greater detail herein. As shown, the adapted normalized deceleration ($D_{adapted}$), the normalized total powertrain output power (P_{norm}), and the normalized braking percentage (Pct_Brk_{norm}) may be fuzzy input variables (x_i).

Input membership functions may be applied to the normalized fuzzy inputs (x_i) at fuzzification block **72**. With general reference to FIGS. **5***a-c*, exemplary input membership functions ($\tilde{D}_{i,j}$) for the fuzzy input variables (x_i) are illustrated in accordance with one or more embodiments of the present application. As shown, each fuzzy input (x_i) may have a corresponding input membership function ($\tilde{D}_{i,j}$) having two truth values—one for LOW and one for HIGH. The truth values may be referred to herein as input membership values, $\mu_j(x_i, \tilde{D}_{i,j})$. Thus, each input membership function ($\tilde{D}_{i,j}$) may be used to generate the input membership values, $\mu_j(x_i, \tilde{D}_{i,j})$, for fuzzy rule antecedents of "LOW" and "HIGH" for a given normalized fuzzy input (x_i). With specific reference to FIG. **5***a*, an input membership function ($\tilde{D}_{1,j}$) for use in generating input membership values, $\mu_j(x_1, \tilde{D}_{1,j})$, for the normalized braking percentage fuzzy input (x_1=Pct_Brk_{norm}) is illustrated. As an example, vertical line **74** may represent a particular normalized braking percentage input value (x_1). As shown, the input membership value for the antecedent of "LOW" may be 0.8, while the input membership value for the antecedent of "HIGH" may be 0.2.

FIG. **5***b* illustrates an input membership function ($\tilde{D}_{2,j}$) for use in generating input membership values, $\mu_j(x_2, \tilde{D}_{2,j})$, for the adapted normalized declaration fuzzy input (x_2=$D_{adapted}$). Vertical line **76** may represent a particular adapted normalized deceleration input value (x_2). As shown in this example, the input membership value for the antecedent of "LOW" may be 0.9, while the input membership value for the antecedent of "HIGH" may be 0.1. FIG. **5***c* illustrates an input membership function ($\tilde{D}_{3,j}$) for use in generating the input membership values, $\mu_j(x_3, \tilde{D}_{3,j})$, for the normalized total powertrain output power fuzzy input (x_3=P_{norm}). Vertical line **78** may represent a particular normalized total powertrain output power input value (x_3). As shown in the example, the input membership value for the antecedent of "LOW" may be 0.4, while the input membership value for the antecedent of "HIGH" may be 0.6.

Referring back to FIG. **4**, the fuzzy logic controller may apply a set of fuzzy rules at block **80** for use in generating a plurality of output membership values ($\tilde{h}_{k,j}$). FIG. **6** shows a table **82** illustrating an exemplary set of fuzzy rules in accordance with one or more embodiments of the present application. In the illustrated embodiment, eight (8) fuzzy rules are shown corresponding to the number of event multiples for the three normalized fuzzy inputs for braking percentage (x_1), adapted normalized deceleration (x_2), and normalized total powertrain output power (x_3), each of which has two possible outcomes (e.g., HIGH or LOW). Each row in table **82** below a header **84** may correspond to a different fuzzy rule, the j-th rule. Table **82** may include three antecedent columns **86** after a rule number column **88**. The antecedent columns **86** generally depict the rule antecedents for the three fuzzy input variables (x_i): normalized braking percentage (x_1), adapted normalized deceleration (x_2), and normalized total powertrain output power (x_3). As described above, the rule antecedents may relate to the input membership values, $\mu_j(x_i, \tilde{D}_{i,j})$

Each fuzzy rule in the illustrated embodiment may also have three rule consequents. Accordingly, table **82** may further include three consequent columns **90** adjacent to the antecedent columns **86**. The three rule consequents may correspond to three fuzzy output variables, referred to as defuzzified outputs (y_k), which can be used to determine the instantaneous deceleration score (S_d). According to one or more embodiments, the three fuzzy output variables may include an advised change in deceleration score (y_1), a maximum deceleration score offset (y_2), and a minimum deceleration score offset (y_3). The advised change in deceleration score output (y_1) may correspond to a recommended change in braking power requested by the driver via the brake pedal. The maximum deceleration score offset output (y_2) may correspond to a maximum advised change in the driver requested braking power. The minimum braking power offset output (y_3) may correspond to a minimum advised change in the driver requested braking power. Since the ultimate output to the fuzzy logic algorithm **70** is the instantaneous deceleration score (S_d), the advised change in deceleration score may generally correspond to a change in the instantaneous deceleration score, as will be described in greater detail below.

The rule consequents may be used in the generation of the output membership values ($\tilde{h}_{k,j}$). For instance, each fuzzy output variable (y_k) may be associated with an output membership function for determining the output membership values ($\tilde{h}_{k,j}$) used to calculate the defuzzified output values. FIG. **7** depicts a simplified, exemplary output membership function **92** for determining the output membership value ($\tilde{h}_{1,j}$) for a given rule consequent of the advised change in deceleration score fuzzy output variable (y_1). As seen therein, the output membership value for the consequent of "HIGH" may be 0.5, whereas the output membership value for the consequent of "LOW" may be 0.1. The output membership value for the consequent of "−HIGH" may be −0.5, whereas the output membership value for the consequent of "−LOW" may be −0.1. Although FIG. **7** depicts an exemplary output membership function for determining output membership values ($\tilde{h}_{k,j}$) for the advised change in deceleration score rule consequents (where k=1), similar output membership functions may be applied for determining the output membership values associated with the maximum deceleration score offset and minimum deceleration score offset rule consequents. Alternatively, the maximum and minimum deceleration score offsets may be optional fuzzy logic output variables. In this manner, all the rule consequents for the maximum deceleration score offset output (y_2) may effectively be HIGH (where HIGH=1). Similarly, all the rule consequents for the minimum deceleration score offset output (y_3) may effectively be LOW (where LOW=0). Moreover, different output membership values ($\tilde{h}_{1,j}$) than those that are shown may be provided by output membership function **92** for the rule consequents for the advised change in deceleration score fuzzy output variable, depending upon the particular implementation.

Referring back to FIG. **6**, table **82** may further include a comments column **94**, which provides a brief description of the braking deceleration behavior conditions satisfying each fuzzy rule and, in some instances, a proposed system response for providing feedback to the driver when the conditions are met. For instance, with reference to the first fuzzy rule (j=1), the system may provide positive instantaneous deceleration behavior feedback when the braking percentage is in the low range, the vehicle deceleration is in the low range, and the total power is in the low range. This scenario may occur when braking is performed in the most efficient manner.

With reference to the second fuzzy rule (j=2), the system may provide relatively slow positive instantaneous deceleration behavior feedback when the braking percentage is in the low range, the vehicle deceleration is in the low range, and total power is in the higher range. The preceding scenario can occur when braking is performed efficiently, but other conditions causing powertrain power consumption are present. For instance, under colder climate conditions, the powertrain may require more power for heating powertrain components.

With reference to the third fuzzy rule (j=3), the system may provide relatively slow positive instantaneous deceleration behavior feedback when the braking percentage is in the low range, the vehicle deceleration is in the high range, and the total power is in the low range. This scenario may cover a predictive condition when the current braking behavior is not causing an inefficiency (e.g., when the vehicle is going uphill while being braked) but may require more attention from the driver if this condition changes.

With reference to the fourth fuzzy rule (j=4), the system may prepare to provide an anticipated slow negative instantaneous deceleration behavior feedback when the percent braking is in low range, the vehicle deceleration is in the high range, and the total power is in the high range. This case covers conditions where current braking behavior is relatively efficient, but the system predicts that the operation will become inefficient if the driver continues this braking behavior. Therefore, the system may anticipate this condition and be ready to inform the driver of this upcoming inefficiency.

With reference to the fifth fuzzy rule (j=5), the system may prepare to provide slow negative instantaneous deceleration behavior feedback when the braking percentage is in the high range, the vehicle deceleration is in the low range, and the total power is in the low range. This scenario may cover conditions where the current braking behavior is not desirable, but the deceleration and total power are low (e.g., when the vehicle is going downhill). The system may predict that if the driver was to continue this braking behavior, the operation will become inefficient. Therefore, the system will need to be ready to inform the driver of this upcoming inefficiency.

With reference to the sixth fuzzy rule (j=6), the system may anticipate a condition for providing slow negative instantaneous deceleration behavior feedback when the braking percentage is in the high range, the vehicle deceleration is in the low range, and the total power is in the high range. This case can occur when a vehicle is going downhill, the powertrain is consuming more power, and the braking is undesirable. As a result, the vehicle deceleration is already low despite the higher braking range. This condition may not necessarily result in energy inefficiency, but system shall prepare for a possible inefficiency if such condition was to disappear.

With reference to the seventh fuzzy rule (j=7), the system may provide a negative instantaneous deceleration behavior feedback when the braking percentage is in the high range, the vehicle deceleration is in the high range, and the total power is in the low range. This case may occur when a vehicle is under heavy braking and, as a result, vehicle deceleration may be high. Therefore, such current conditions can result in energy inefficiency.

With reference to the eighth fuzzy rule (j=8), the system may provide a negative instantaneous deceleration behavior feedback when the braking percentage is in the high range, the vehicle deceleration is in the high range, and the total power is in the high range. This scenario may occur when a vehicle is undergoing heavy braking and the powertrain is also producing more power (e.g., as result of the accelerator pedal also being engaged or the powertrain being cold). Therefore, such current condition may result in further energy inefficiency.

According to one or more embodiments of the present application, the j-th rule operation may be represented using the following expression:

$$\mu_j(x_1,\tilde{D}_{1,j})\mu_j(x_2,\tilde{D}_{2,j})\mu_j(x_3,\tilde{D}_{3,j})$$

Where:

x_i=normalized fuzzy input variables (i=1, 2, 3)

$\tilde{D}_{i,j}$=input membership functions

$\mu_j(x_i, \tilde{D}_{i,j})$=input membership value of the rule antecedent of the j-th rule for a given normalized input (x_i) and its corresponding input membership function ($\tilde{A}_{i,j}$)

Referring back to FIG. **4**, once determined, the output membership value sets ($\tilde{h}_{k,j}$) and the input membership value sets ($\mu_j(x_i, \tilde{D}_{i,j})$) may undergo defuzzification at block **96**. At defuzzification block **96**, fuzzy operator implication and aggregation may occur using the input and output membership value sets. The controller **22** may calculate the outputs of defuzzification (y_k) according to Eq. 10 as set forth below:

$$y_k = \frac{\sum_{j=1}^{\Omega}\mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})\tilde{h}_{k,j}}{\sum_{j=1}^{\Omega}\mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})}; \quad k = 1, 2, 3 \qquad \text{Eq. 10}$$

Where:

Ω=total number of fuzzy rules (e.g., eight)

x_i=normalized fuzzy input variables (i=1, 2, 3)

$\tilde{D}_{i,j}$=input membership functions

$\mu_j(x_i, \tilde{D}_{i,j})$=input membership value of the rule antecedent of the j-th rule for a given normalized input (x_i) and its corresponding input membership function ($\tilde{A}_{i,j}$)

$\tilde{h}_k$,j=output membership value of the rule consequent of the j-th rule for a given fuzzy output variable and its corresponding output membership function

As set forth above, the controller **22** may generate three (3) defuzzified outputs (y_k) at defuzzification block **96**. Moreover, the three defuzzified outputs (y_k) may be associated with the three rule consequents shown by table **82** in FIG. **6**, namely: the advised change in deceleration score, the maximum deceleration score offset, and the minimum deceleration score offset.

FIG. **8** is an exemplary flow diagram illustrating an implementation of the defuzzification algorithm using a real-world example. Table **98** demonstrates how a denominator **100** from Eq. 10 may be calculated. As shown in table **98**, the antecedents of "LOW" and "HIGH" for each fuzzy rule have been replaced by the corresponding input membership values, $\mu_j(x_i, \tilde{D}_{i,j})$, for each normalized input (x_i) and its input membership function ($\tilde{D}_{i,j}$). In this example, the input membership values in table **98** correspond to the input membership values obtained using the input membership functions shown in FIGS. **5***a-c* for the particular normalized inputs (x_i) depicted by vertical lines **74**, **76**, **78**. These input membership values may become the antecedent operators for the j-th rule operation, $\mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})$, as shown in column **102**. The results of the j-th rule operations are shown in column **104**. The results of the j-th rule operations may be aggregated. The sum of the j-th rule operations is shown at the bottom of column **104** in cell **106**. The sum of the results of the j-th rule operations becomes the denominator **100** for calculating the defuzzified outputs (y_k) as set forth in Eq. 10. As shown, the summation for the j-th rule operations is equal to one (1).

Table **108** demonstrates how a numerator **110** from Eq. 10 may be calculated. As shown in table **108**, the consequents of "LOW," "HIGH," "–LOW" and "–HIGH" may be replaced by the corresponding output membership values ($\tilde{h}_{k,j}$) for each fuzzy output variable (where k=1, 2, 3) and its corresponding output membership function. For explanation purposes, in this example, table **108** only shows the output membership value set ($\tilde{h}_{1,j}$) for use in calculating the numerator **110** of the defuzzified output (y_1), which corresponds to the advised change in braking power output variable (where k=1). However, the numerator **110** for each defuzzified output (y_k) may be calculated in a similar fashion using the associated output membership value sets ($\tilde{h}_{k,j}$). In this example, the output membership values ($\tilde{h}_{1,j}$) may correspond to the exemplary output membership values obtained from the sample output membership function **92** shown in FIG. **7**. By way of fuzzy implication, each result from the j-th rule operation, $\mu_j(x_1, \tilde{D}_{1,j})\mu_j(x_2, \tilde{D}_{2,j})\mu_j(x_3, \tilde{D}_{3,j})$, may be multiplied by its corresponding output membership value ($\tilde{h}_{1,j}$), as shown in column **112**. The results of the fuzzy implications are shown in column **114**. The results of the fuzzy implications may also be aggregated. The sum of the aggregated results is shown at the bottom of column **114** in cell **116**. The sum of the results of the fuzzy implications becomes the numerator **110** for the defuzzified outputs (y_k) as set forth in Eq. 10. As shown in FIG. **8**, in this example, the numerator **110** for the defuzzified output (y_1) is equal to 0.1656.

Referring back to FIG. **4**, once all the defuzzified outputs (y_k) are generated at defuzzification block **96**, the controller **22** may determine the fuzzy logic output as provided at block **118**. As shown, the fuzzy logic output may be the instantaneous deceleration score (S_d). The controller **22** may calculate the instantaneous deceleration score (S_d) from the defuzzified outputs (y_k) according to Eq. 11 and Eq. 12 as set forth below:

$$S_{tmp} = \int y_1 dt \qquad \text{Eq. 11}$$

$$S_d = \begin{cases} 1 + y_2, & \text{if } S_{tmp} > (1 + y_2) \\ S_{tmp}, & \text{if } y_3 \le S_{tmp} \le (1 + y_2) \\ y_3, & \text{if } S_{tmp} < y_3 \end{cases} \qquad \text{Eq. 12}$$

Where:

y_k=defuzzified outputs (k=1, 2, 3)

y_1: advised change in deceleration score

y_2: max deceleration score offset

y_3: min deceleration score offset

Once determined, the instantaneous deceleration score (S_d) may be transmitted to the user interface **24** and conveyed to a driver using display **30**. The instantaneous deceleration score (S_d) may be conveyed to the driver using the deceleration feedback gauge **32***b*. According to one or more embodiments, the location of the deceleration feedback indicator **36** along the deceleration feedback gauge **32***b* may correspond to the instantaneous deceleration score (S_d). Additionally or alternatively, the color of at least a portion of the deceleration feedback gauge **32***b* may be associated with the instantaneous deceleration score (S_d). For instance, when the instantaneous deceleration score (S_d) is within a first range, at least a portion of the deceleration feedback gauge **32***b* may be displayed in a first color. Further, when the instantaneous deceleration score (S_d) is within a second range, at least a portion of the deceleration feedback gauge **32***b* may be displayed in a second color different from the first. Moreover, when the instantaneous deceleration score (S_d) is within a third range, at least a portion of the deceleration feedback gauge **32***b* may be displayed in a third color, which may be different from the first and second color. Fewer or greater instantaneous deceleration score ranges and associated colors may be implemented to convey the instantaneous deceleration score (S_d) in accordance with one or more embodiments of the present application.

Additionally, as previously described, the instantaneous deceleration score (S_d) may be used to calculate the long-term deceleration score (L_d) as set forth above in Eq. 9. The long-term deceleration score (L_d) may be transmitted to the user interface **24** and conveyed to a driver using display **30**. The long-term deceleration score (L_d) may be conveyed to the driver using the deceleration feedback gauge **32***b*. According to one or more embodiments, the location of the deceleration feedback indicator **36** along the deceleration feedback gauge **32***b* may correspond to the long-term deceleration score (L_d). In this case, the instantaneous deceleration score (S_d) may be conveyed by the user interface **24** in another manner (e.g., the color of at least a portion of the deceleration feedback gauge **32***b*), or not at all. Additionally or alternatively, the color of at least a portion of the deceleration feedback gauge **32***b* may also be associated with the long-term deceleration score (L_d).

FIG. **9** is a simplified, exemplary flow chart **900** depicting a method for conveying braking deceleration behavior feedback in accordance with one or more embodiments of the present application. At step **905**, the system may receive inputs such as input signals **26**. The input signals **26** may be generally indicative of vehicle speed (V_{spd}), vehicle deceleration (D_{actual}), total powertrain output power (P_{total}), and/or the braking percentage (Pct_Brk). Exemplary input signals may include the brake switch signal (Brk_SW), the brake pedal flag signal (Brk_Ped_Flg), friction braking torque ($T_{friction}$), regenerative braking torque (T_{regen}), high-voltage (HV) battery power (P_{batt}), fuel flow rate (Fuel_Flow), vehicle speed (V_{spd}) and/or output shaft speed (ω_{oss}), (and the like. The system may compute vehicle deceleration (D_{actual}), total powertrain output power (P_{total}), and/or the braking percentage (Pct_Brk) from the input signals **26** at step **910**. The vehicle deceleration (D_{actual}) may be calculated from the vehicle speed (V_{spd}) and/or output shaft speed (ω_{oss}). The total powertrain output power (P_{total}) may be calculated differently depending upon the powertrain configuration. In general, the total powertrain output power (P_{total}) may be the sum of the battery power (P_{batt}) and fuel power (P_{fuel}). However, depending upon the powertrain technology, either the battery power (P_{batt}) or fuel power (P_{fuel}) may be equal to zero. The braking percentage (Pct_Brk) may be determined from one or more of the following inputs depending upon the powertrain configuration: the brake switch signal (Brk_SW), the brake pedal flag signal (Brk_Ped_Flg), friction braking torque ($T_{friction}$), regenerative braking torque (T_{regen}), and the like.

At step **915**, the vehicle deceleration (D_{actual}), total powertrain output power (P_{total}), and accelerator pedal position change (ΔAcc_Ped) may be normalized. In particular, the vehicle acceleration (A_{actual}), total powertrain output power (P_{total}), and braking percentage (Pct_Brk) may be modified as a function of vehicle speed (V_{spd}) to obtain the normalized acceleration (D_{norm}), the normalized total powertrain output power (P_{norm}), and the normalized braking percentage (Pct_Brk_{norm}), respectively. The deceleration, total powertrain output power, and braking percentage may be normalized with respect to vehicle speed to adjust for vehicle behavior and operating characteristics at different speeds, as well as account for the vehicle speed when determining the braking deceleration behavior feedback.

At step **920**, system may determine whether a braking event has occurred or is occurring. The system may convey braking deceleration behavior feedback when a braking event is detected. According to one or more embodiments, a braking event may be detected when the braking percentage is above a braking percentage threshold, the vehicle speed is above a speed threshold, and the vehicle deceleration is above a deceleration threshold. If no braking event is detected, the method may return to step **905** where the input signals **26** can continue to be monitored. If, on the other hand, a braking event is detected at step **920**, the method may proceed to step **925**.

At step **925**, the system may calculate the adapted normalized deceleration ($D_{adapted}$). According to one or more embodiments, the normalized deceleration input (D_{norm}) may be modified based on driver responsiveness to the braking deceleration behavior feedback. In this regard, the normalized deceleration (D_{norm}) may be multiplied by the long-term deceleration score (L_d) to generate the adapted normalized deceleration ($D_{adapted}$). At step **930**, the system may calculate the instantaneous deceleration score (S_d) based upon the adapted normalized deceleration ($D_{adapted}$), the normalized total powertrain output power (P_{norm}), and the normalized braking percentage (Pct_Brk_{norm}). In one or more embodiments, the instantaneous deceleration score (S_d) may be output to the user interface **24** where it may be conveyed to a driver, as provided at step **935**. The instantaneous deceleration score (S_d) may be conveyed to the driver using the deceleration feedback gauge **32***b*. According to one or more embodiments, the location of the deceleration feedback indicator **36** along the deceleration feedback gauge **32***b* may correspond to the instantaneous deceleration score (S_d). Additionally or alternatively, the color of at least a portion of the deceleration feedback gauge **32***b* may be associated with the instantaneous deceleration score (S_d).

Additionally, the instantaneous deceleration score (S_d) may be compared to a function of the long-term deceleration score ($f(L_d)$) to determine whether the driver's instantaneous braking deceleration behavior will increase or decrease the long-term deceleration score (L_d), at step **940**. According to one or more embodiments, $f(L_d)$ may be set equal to L_d. In this manner, if the instantaneous deceleration score (S_d) is greater than the long-term deceleration score (L_d), the system may conclude that the long-term deceleration score is increasing. Accordingly, the system may select an increasing forgetting factor (w_i) at step **945**. If, on the other hand, the instantaneous deceleration score (S_d) is less than the long-term deceleration score (L_d), the system may conclude that the long-term deceleration score is decreasing. Accordingly, the system may select a decreasing forgetting factor (w_d) at step **950**. The instantaneous deceleration score (S_d) may be compared to alternative functions of the long-term deceleration score ($f(L_d)$) to determine whether the driver's instantaneous deceleration behavior will increase or decrease the long-term deceleration score (L_d). Once the appropriate forgetting factor (w) is selected, the method may proceed to step **955**.

At step **955**, the system may compute a new long-term deceleration score (L_d). According to one or more embodiments of the present application, the new long-term deceleration score (L_d) may be based upon the previous long-term deceleration score, the instantaneous deceleration score (S_d), and the selected forgetting factor (w) according to Eq. 9 set forth above. Once calculated, the long-term deceleration score (L_d) may be output to the user interface **24** where it may be conveyed to a driver, as provided at step **960**. The long-term deceleration score (L_d) may be conveyed to the driver using the deceleration feedback gauge **32***b*. According to one or more embodiments, the location of the deceleration feedback indicator **36** along the deceleration feedback gauge **32***b* may correspond to the long-term deceleration score (L_d). In this case, the instantaneous deceleration score (S_d) may be conveyed by the user interface **24** in another manner (e.g., the color of at least a portion of the deceleration feedback gauge **32***b*), or not at all. Additionally or alternatively, the color of at least a portion of the deceleration feedback gauge **32***b* may also be associated with the long-term deceleration score (L_d).

FIG. **10** is a simplified, exemplary flowchart **1000** depicting the process for calculating the instantaneous deceleration score (S_d) at step **930** in FIG. **9** in greater detail in accordance with one or more embodiments of the present application. As previously described, the instantaneous deceleration score (S_d) may be calculated using a fuzzy logic algorithm. To this end, input membership functions ($\tilde{D}_{i,j}$) may be applied to obtain input membership values, $\mu_j(x_i, \tilde{D}_{i,j})$, for a given set of normalized fuzzy input variables (x_i), at step **1010**. At step **1020**, the set of fuzzy logic rules may be applied to obtain the rule consequents for use in generating the set of output membership values ($\tilde{h}_{k,j}$). At step **1030**, an output membership function may be applied to the fuzzy rule consequents for each fuzzy output variable to obtain the output membership values ($\tilde{h}_{k,j}$). At step **1040**, the system may calculate the defuzzified outputs (y_k) for each fuzzy output variable according to Eq. 10 set forth above. The first defuzzified output (y_1) may correspond to an advised change in driver requested braking power or deceleration score. The second defuzzified output (y_2) may correspond to a maximum deceleration score offset. The third defuzzified output (y_3) may correspond to a minimum deceleration score offset. At step **1050**, the system may calculate the instantaneous deceleration score (S_d) based upon the defuzzified outputs (y_k) according to Eq. 11 and Eq. 12 set forth above. Once the instantaneous deceleration score (S_d) is calculated, the method may return to step **940** in FIG. **9** for the calculation of the long-term deceleration score (L_d).

While exemplary embodiments are described above, it is not intended that these embodiments describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention. Additionally, the features of various implementing embodiments may be combined to form further embodiments of the invention.

What is claimed is:

1. A system comprising:

a controller configured to receive input indicative of vehicle deceleration and powertrain output power, calculate an instantaneous deceleration score based upon the input, and output a long-term deceleration score based upon the instantaneous deceleration score, a previous long-term deceleration score, and a forgetting factor for weighting the instantaneous deceleration score and the previous long-term deceleration score; and

an interface configured to display a deceleration feedback indicator indicative of the long-term deceleration score.

2. The control system of claim **1**, wherein the interface includes a deceleration feedback gauge for displaying the deceleration feedback indicator, and wherein the interface is configured to adjust the deceleration feedback indicator within the deceleration feedback gauge based on the long-term deceleration score.

3. The control system of claim **2**, wherein the interface is further configured to adjust a color of at least a portion of the deceleration feedback gauge based on the instantaneous deceleration score.

4. The control system of claim **2**, wherein the interface is further configured to adjust a color of at least a portion of the deceleration feedback gauge based on the long-term deceleration score.

5. The control system of claim **1**, wherein the input is further indicative of a braking percentage.

6. The control system of claim **5**, wherein the controller is further configured to calculate the instantaneous deceleration score based upon the vehicle deceleration, the powertrain output power and the braking percentage.

7. The control system of claim **6**, wherein the controller is further configured to normalize one or more of the vehicle deceleration, the powertrain output power and the braking percentage based upon vehicle speed prior to calculating the instantaneous deceleration score.

8. The control system of claim **6**, wherein the controller is further configured to calculate an adapted deceleration value prior to calculating the instantaneous deceleration score, the adapted deceleration value being based on the vehicle deceleration and the long-term deceleration score.

9. The control system of claim **8**, wherein the adapted deceleration value is calculated by multiplying a normalized deceleration value by the long-term deceleration score.

10. The control system of claim **8**, wherein the instantaneous deceleration score is calculated using a fuzzy logic algorithm.

11. The control system of claim **1**, wherein the forgetting factor is based on whether the previous long-term deceleration score is less than the instantaneous deceleration score.

12. A method comprising:

receiving input indicative at least of vehicle deceleration and powertrain output power;

calculating an instantaneous deceleration score based upon the input;

calculating a long-term deceleration score based upon the instantaneous deceleration score, a previous long-term deceleration score, and a forgetting factor for weighting the instantaneous deceleration score and the previous long-term deceleration score; and

displaying a deceleration feedback gauge having a deceleration feedback indicator indicative of the long-term deceleration score.

13. The method of claim **12**, wherein the input is further indicative of a braking percentage.

14. The method of claim **13**, further comprising:
normalizing one or more of the vehicle deceleration, the powertrain output power and the braking percentage based upon vehicle speed prior to calculating the instantaneous deceleration score.

15. The method of claim **13**, further comprising:
calculating an adapted deceleration value prior to calculating the instantaneous deceleration score, the adapted deceleration value being based on the vehicle deceleration and the long-term deceleration score.

16. The method of claim **13**, further comprising:
adjusting a color of at least a portion of the deceleration feedback gauge based on the instantaneous deceleration score.

17. The method of claim **12**, further comprising:
adjusting a color of at least a portion of the deceleration feedback gauge based on the long-term deceleration score.

18. A display control system comprising:
a controller configured to receive input indicative of an adapted vehicle deceleration value, powertrain output power and braking percentage, calculate an instantaneous deceleration score based on the input, and provide a deceleration feedback signal corresponding to a long-term deceleration score based upon the instantaneous deceleration score; and
a display in communication with the controller and including a deceleration feedback gauge configured to display a deceleration feedback indicator indicative of the long-term deceleration score;
wherein the adapted vehicle deceleration value is based on current vehicle deceleration and a previous long-term deceleration score.

19. The display system of claim **18**, wherein the display is further configured to adjust a color of at least a portion of the deceleration feedback gauge based on the long-term deceleration score.

20. The display system of claim **18**, wherein the display is further configured to adjust a color of at least a portion of the deceleration feedback gauge based on the instantaneous deceleration score.

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